A Market Outlook on Sustainable Aviation Fuel

Background analysis

May 2022

SkyNRG

This background analysis contains 4 sections

1. **Comparison with previous SAF Market Outlook**
Tracks changes in major conclusions from the last version of the Market Outlook on Sustainable Aviation Fuel (published in July 2021).

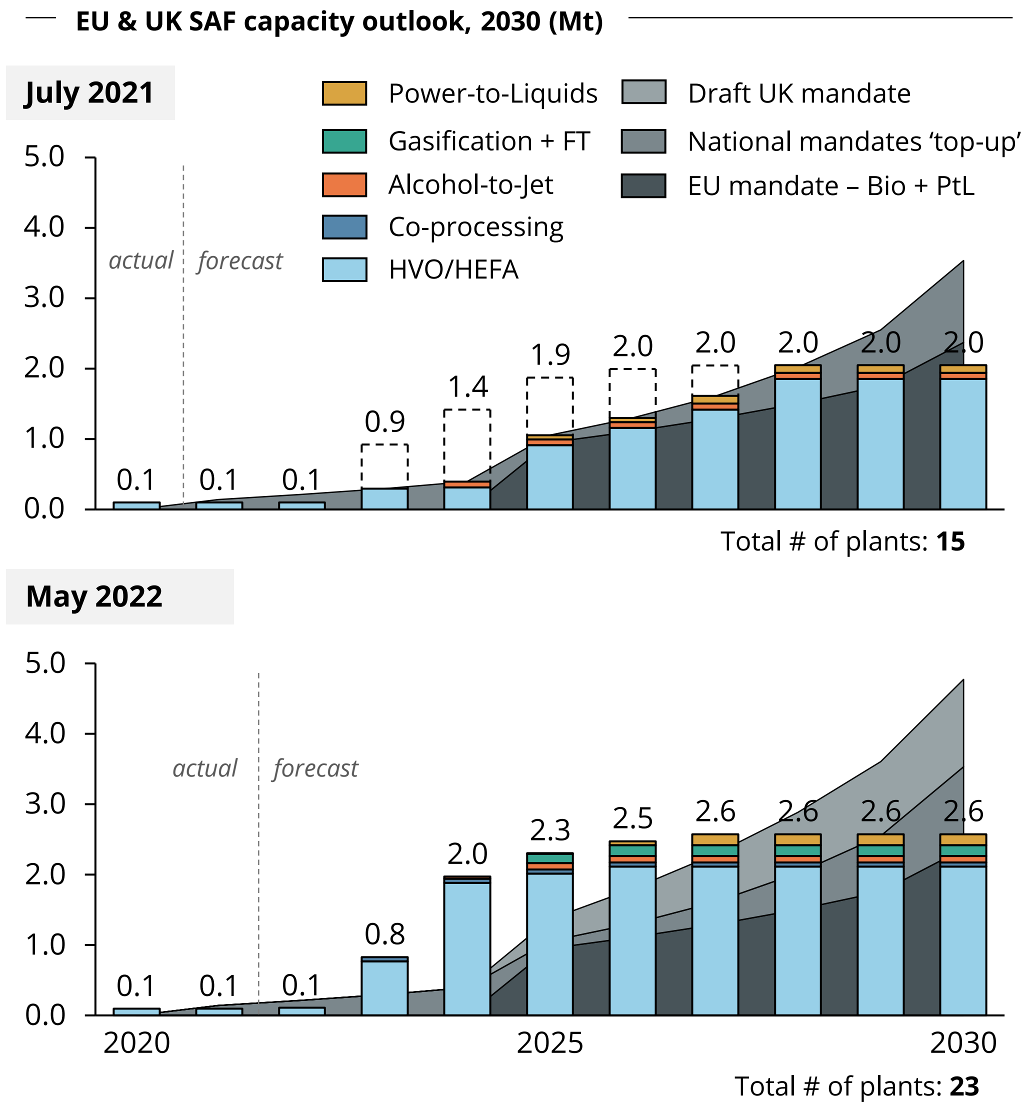
2. **European (EU-27 + UK) SAF Outlook**
Details the EU and UK analysis. Includes an overview of the mandates before going into SAF supply based on plant announcements (up to 2030) and modelling (up to 2050). This part is largely an update from the previous Market Outlook.

3. **United States SAF Outlook**
Details the US analysis, from SAF policy to expected SAF supply based on plant announcements. This part is completely new compared to the previous Market Outlook.

4. **Methodological Annex**
Containing more detailed assumptions and explanation of methodology.

1. Comparison with previous SAF Market Outlook

Since the previous outlook 6 months ago, proposed mandates in Europe increased to 4.6 Mt in 2030. Announcements bring projected supply to 2.6 Mt in 2030



Changes in assumptions, inputs and visualization

- Scope of the assessment was expanded to the UK, meaning:
  - Draft UK mandate was added, leading to additional demand
  - UK capacity announcements have been added
- Power-to-Liquids has been included on the supply side, despite there not being a mandate in place for PtL prior to 2030
- Expected volumes coming from EU plants are not cut off at mandated volumes anymore, as it is expected this supply is absorbed by the voluntary market or exported to other compliance markets

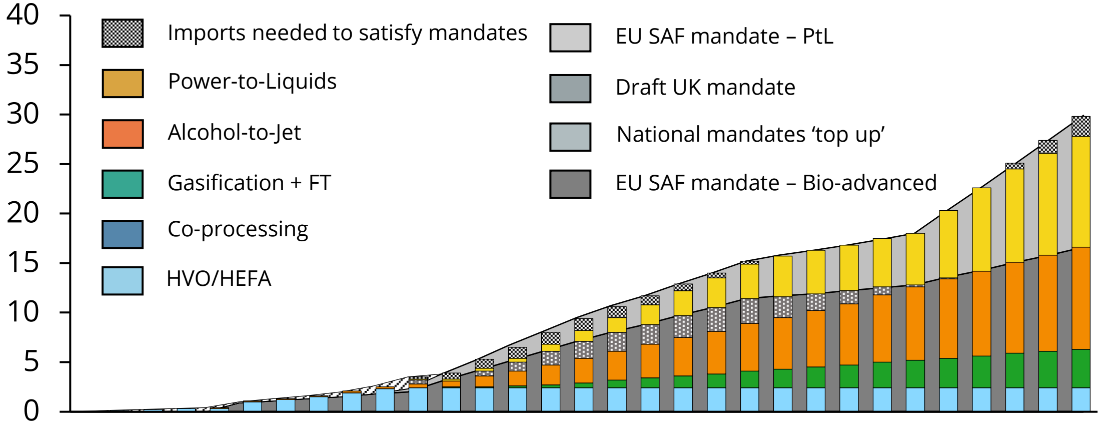
Key takeaways

- Due to the addition of the draft UK mandate, demand for SAF in Europe is expected to increase by 1.2 Mt in 2030, to 4.6 Mt SAF
- Even when subtracting UK-based announcements, the gap to meeting the EU bio-SAF target by 2030 is fully closed
- Announcements to fulfil the synthetic aviation fuel (PtL) sub-mandate, which kicks in by 2030 at 0.7%, are about 170 kt short
- European and UK announcements can grow further by about 2.2 Mt until expected mandated demand would be fully saturated

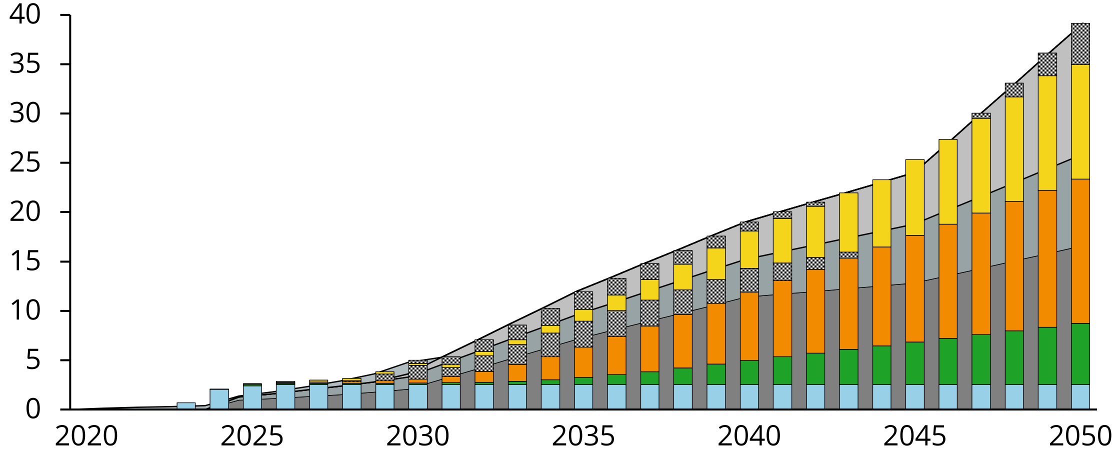
With the addition of the draft UK mandate, a SAF demand of 40 Mt is expected on the European continent by 2050 vs. 30 Mt in the previous outlook

EU & UK SAF capacity outlook, 2050 (Mt)

July 2021



May 2022



Changes in assumptions, inputs and visualization

- Scope of the assessment was expanded to the UK, meaning:
  - Draft UK mandate was added, leading to additional demand
  - Potential for SAF deployment in UK is added until 2050
- Supply that is exceeding the mandated demand for certain years was previously cut off, but is now shown under the assumption this will be supplied to fulfil non-European mandates or voluntary volumes

Key takeaways

- Due to proposed mandates, demand for SAF in Europe is expected to increase to 40 Mt by 2050
- Because there is a cap on the amount of waste oil for the HVO/HEFA pathway, dependence on the AtJ/G+FT and PtL pathways increased
- Targets for the UK and EU-27 seem feasible, but massive investment in the sector is needed to reach the required scale of deployment
- Imports seem needed, especially in the 2030-2040 phase where targets increase fast growth needs to come from technologies that are not commercial at scale today

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2. European SAF Outlook

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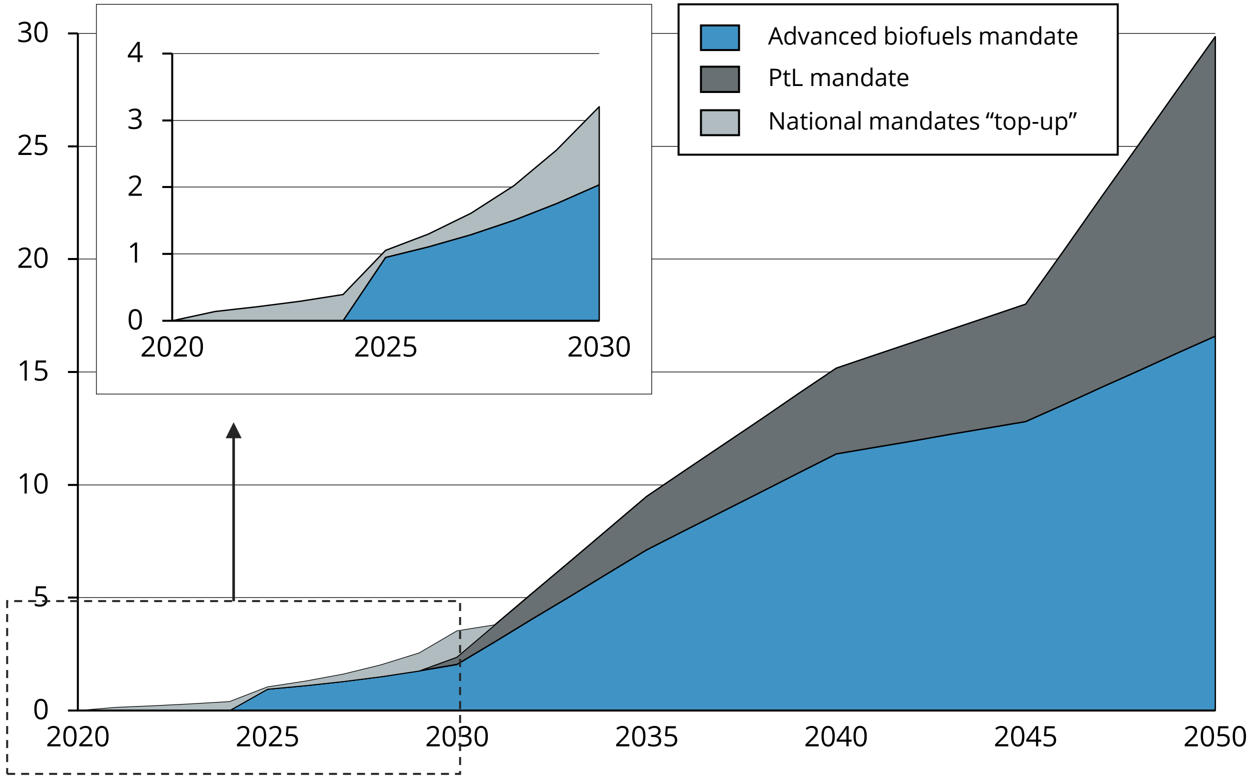
As the legislative process around ReFuelEU progresses, the EU is still anticipated to have a mandated demand of ~30 Mt SAF in 2050

SAF mandates in the EU (Mt SAF)[1]



Please note: Graph does not include voluntary SAF commitments from airlines and corporates

Assumptions

- EU implements a SAF mandate of 2% in 2025, moving to 5% in 2030, 32% in 2040, and 63% in 2050, with split sub-targets for Bio-advanced SAF and Power-to-Liquid (PtL) SAF
- Countries implementing/discussing a more ambitious mandate than the EU (e.g. Sweden) stick to those targets, creating a national mandate "top-up"
- EU jet fuel demand will recover to pre-COVID volumes in 2024, after which it remains constant at 47.4 Mt (2019 level)

Key takeaways

- The RefuelEU mandate for Bio-advanced SAFs increases steeply from 2.0 Mt in 2030 to 11.4 Mt in 2040
- The mandate for PtL SAF accelerates after 2045 to 13.3 Mt in 2050
- Total anticipated mandated volumes are 1 Mt in 2025, 3.5 Mt in 2030 and 30 Mt in 2050
- As of January 2022, there are ongoing discussions in the EU Parliament to increase the ambition of the EU SAF mandate to 100% by 2050, of which 65% would be PtL SAF, as well as introducing a cap on the use of waste oil feedstocks in line with the RED II framework.[2]

[1] Based on: EC, Proposal for a Regulation of the European Parliament and of the Council on ensuring a level playing field for sustainable air transport, 2021 (link), communication on national mandates
[2] Source: EURACTIV (2022)

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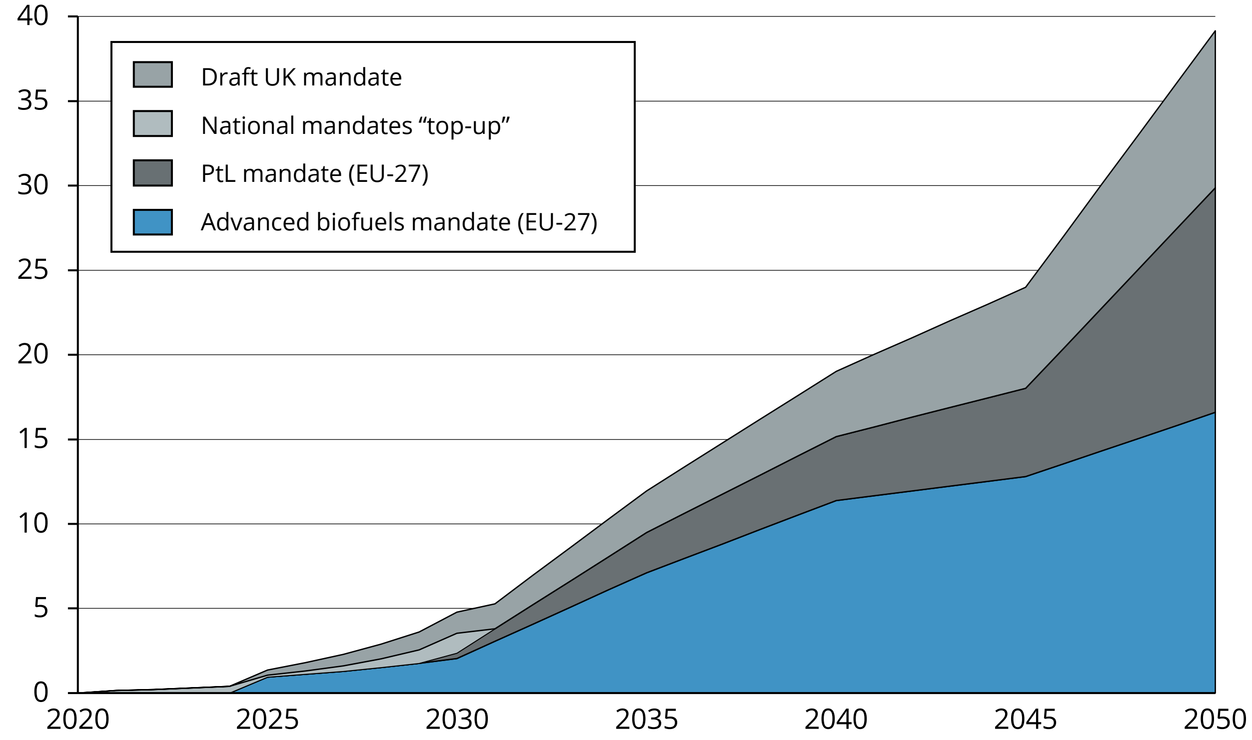
UK swiftly follows EU with an anticipated SAF mandate of ~9 Mt SAF in 2050, which would increase mandated demand in Europe to ~40 Mt

SAF mandates in Europe, including UK (Mt SAF)[1]



Please note: Graph does not include voluntary SAF commitments from airlines and corporates

Assumptions

- The UK held a consultation for a SAF mandate presenting various options from low ambition to early SAF breakthrough
- Currently no split for sub-targets for Bio-advanced SAF and Power-to-Liquid (PtL) SAF have been announced, but are expected
- Eligible feedstocks for SAF production are still to be determined, but will likely follow RTFO guidelines
- Fuel amounts are determined based on relevant expert discussions, combined with the most ambitious scenario in the mandate consultation documents, leading to a SAF mandate of 2.5% in 2025, moving to 10% in 2030, 31.1% in 2040, and 75% in 2050,
- UK jet fuel demand will recover to pre-COVID volumes in 2024 after which it remains constant at 12.4 Mt (2019 level)

Key takeaways

- The UK is currently considering installing a SAF mandate that would start at 10% in 2030, increasing to 75% by 2050 resulting in 9.3 Mt SAF

[1] *Based on: Department for Transport, Sustainable Aviation Fuel Mandate - A consultation on reducing the greenhouse gas emissions of aviation fuels in the UK, Scenario E – Early SAF breakthrough (link)*

A multi-step approach is used to arrive at EU and UK SAF supply projections up to 2050

Step 1
2030 outlook

A — SAF supply from announcements

- Renewable fuel announcements (diesel/jet) are filtered to arrive at a ‘realistic’ SAF projection for 2030. We correct for:
  1. **a realistic SAF yield**;
  2. **projects that do not mention SAF;**
  3. **projects that are unlikely to materialize** (on time)

B — Feedstock/policy sense-checks

- We apply two further sense-checks to the realistic SAF scenario:
  - **policy**: assess demand for renewable fuels from road transport and marine to verify potential ‘capacity switches’
  - **feedstock**: waste oil and fat availability when considering demand from other sectors

C — Closing the supply gap

- Potential for imports, new announcements and extra capacity switches is assessed
- We assume that all production that exceeds mandated demand is taken up by voluntary market or exported

Step 2
2050 outlook

- Few SAF plants are announced today that start after 2027
- To forecast SAF supply till 2050, we developed a capacity growth model, using tested metrics under the WEF Clean Skies for Tomorrow initiative which were chosen after thorough consultation with academics and industry
- Based on in-house knowledge and stakeholder engagement we enriched the analysis to create our own base case for EU & UK SAF supply
- Finally, we run a sensitivity analysis on to discover what are the most impactful drivers in this base case

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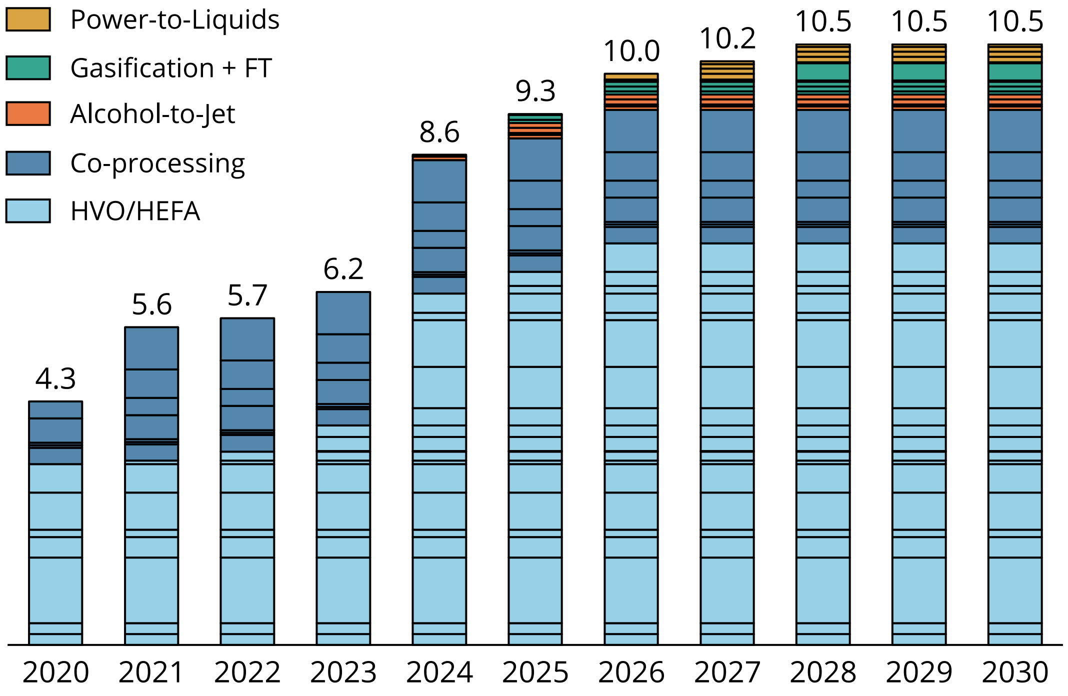
Realistic SAF production in EU/UK is expected to be 2.6 Mt in 2030

Step 1: Renewable fuel capacity

- To go from announced renewable fuel capacity to realistic SAF capacity in the EU + UK, SkyNRG reached out to project and technology developers. We correct for:
  1. **a realistic SAF yield**;
  2. **projects that do not mention SAF;**
  3. **projects that are unlikely to materialize** (on time)

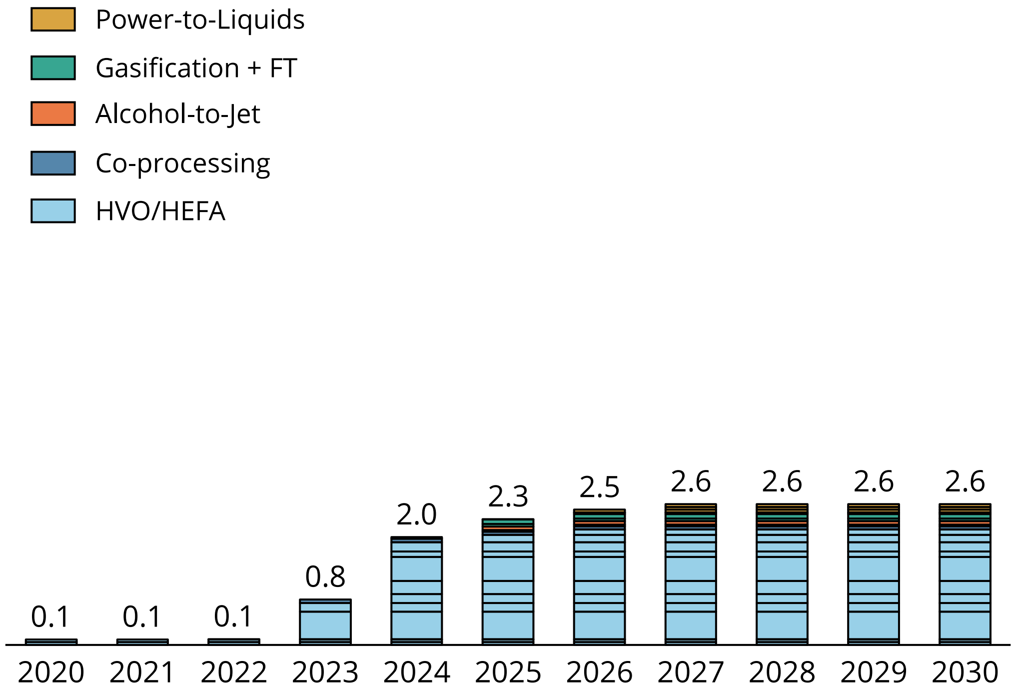
EU + UK advanced renewable fuel capacity (Mt)



Step 2: Realistic SAF capacity

- SAF capacity is estimated to be ~3.9 Mt in 2030 after applying criteria 1 and 2. This can be seen as a technical maximum SAF capacity at that time from SAF announcements.
- A further 1.3 Mt is removed in the third step, coming to a total estimated realistic SAF capacity of **2.6 Mt** in Europe by 2030.

EU + UK SAF capacity (Mt)



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Competing demand check: 1.1 Mt capacity switch from RD to SAF seems possible based on expected RD demand from EU policy

Renewable diesel capacity switching to SAF

Background

- The SkyNRG realistic SAF scenario assumes several capacity switches.[1]
- Such a switch would mean that these plants would produce more SAF and less renewable diesel for the road and maritime sectors.
- Since there are ambitious targets in place for these sectors, such capacity plant switches could conflict with those targets. We therefore perform a cross-check to verify whether the capacity switches are plausible.

Cross-check

A
- EU policies are expected to enable a sustainable diesel (FAME + RD) demand for road and maritime of 15.6 – 25.3 Mt by 2030, based on a review of 22 studies.[2]

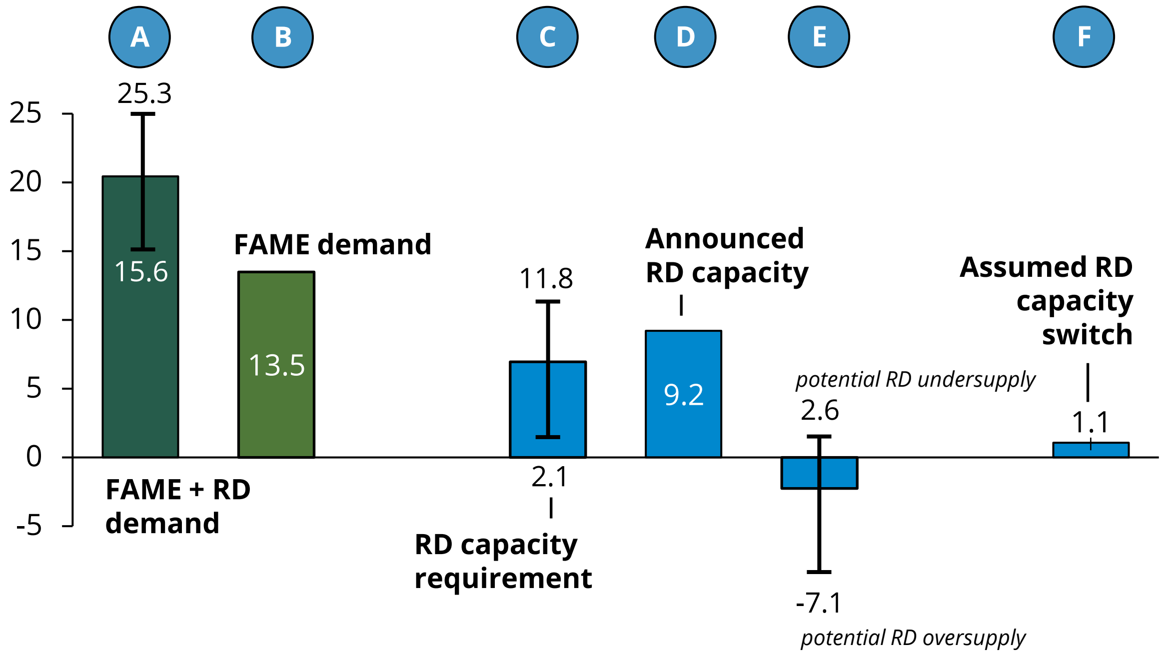
B
- FAME can cover a good share of this: taking into account expected demand from road and maritime, demand for FAME is still expected to stagnate around 13.5 Mt.[3]

C
- Subtracting expected FAME demand from projected demand for sustainable diesel to meet road/maritime targets yields installed RD capacity needed for EU transport targets.

D
- To date, there is 9.2 Mt of announced RD capacity in the EU.

E
- This means that, in the high diesel demand scenario there could be an <u>undersupply</u> of 2.6 Mt, whereas in the low diesel demand scenario there could be an <u>oversupply</u> of 7.1 Mt.

Million tons fuel in 2030



F
- Based on this range, and the possibility of more RD announcements in the coming years, we consider it more likely that RD capacity will be higher than needed for EU transport targets and that the **assumed capacity switches to SAF are plausible.**

[1] A renewable diesel capacity switch is defined as either:
- an operational HVO plant that is producing renewable diesel and is expected to switch part of its production to SAF, or
- a future HVO plant that did not communicate a specific SAF volume, but is expected to produce SAF

[2] *Prussi et al (2022)*
[3] *CONCAWE (2021)*

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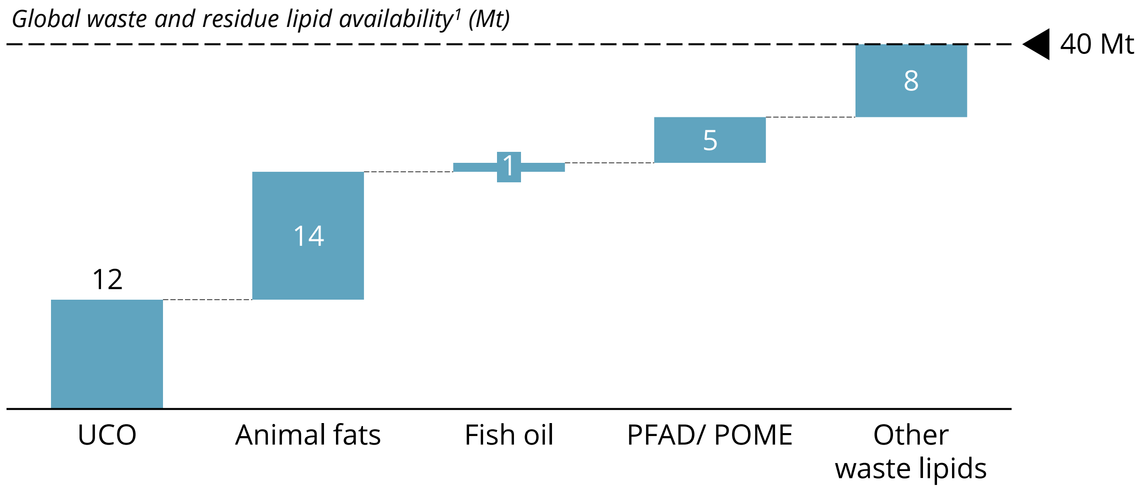
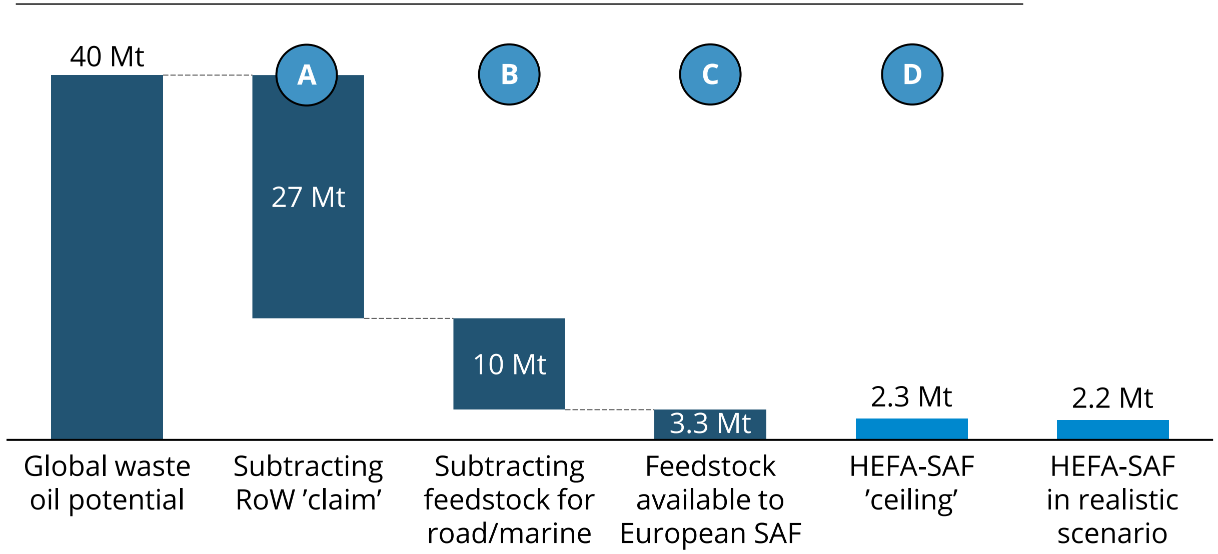
Feedstock check: waste oil availability to SAF in Europe is capped at ~3 Million tons. This is already reached with current announcements





Assumptions

A

- We consider that the EU can likely claim a maximum of a third of the global pool by 2030, which it currently already does for UCO. This means the EU could claim about 13 Mt waste oil feedstock.
- Note that this is about double the feedstock when strictly taking European feedstock availability, which raises concerns over whether at some point regions will want to retain such feedstocks to decarbonize their own transport sectors.

B

- In practice a significant share (at least 10 Mt) of this European waste oil claim will already be required to satisfy EU road and maritime targets (see slide 11).

C

- When we subtract this feedstock demand for road and maritime, we arrive at 3 Mt of waste oils and fats available to the EU SAF sector until 2030. As a result, waste oil feedstock availability to the SAF sector is **capped at around 3 Mt**.
- Any higher demand will lead to feedstock diversion from other transport sectors or other regions of the world, with undesirable associated indirect GHG impacts.
- This is roughly equal to 45 – 70% of all European waste oil supply potential by 2030 (see Appendix slide 36).

D

- Using a 70% conversion ratio of feedstock to jet fuel, HEFA-SAF using waste oil feedstock would be capped in Europe at about 2.3 Mt.
- Based on industry announcements today and expected diesel capacity switches, this ceiling is practically reached in Europe.

[1] Source: *McKinsey/WEF (2020)*

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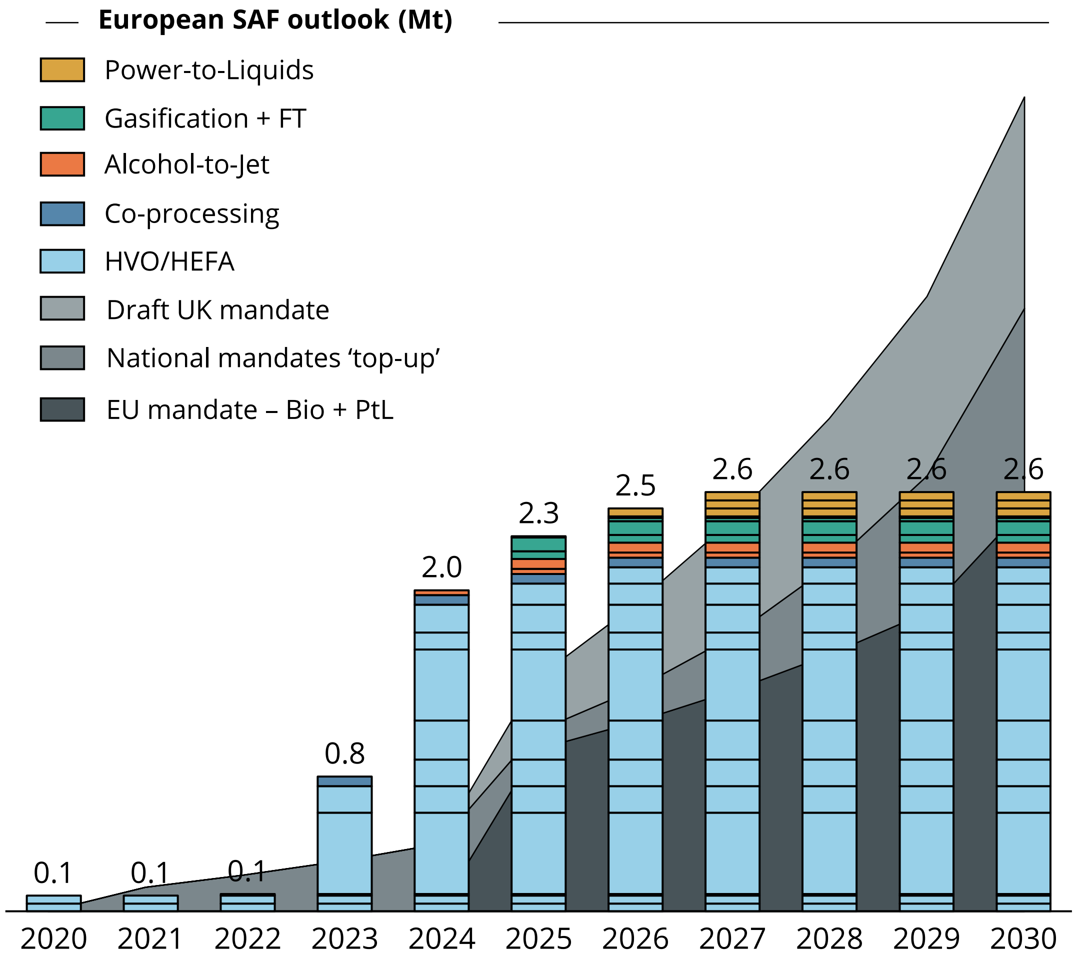
Targets until 2027 seem within reach; gap to meet targets will have to come from cellulosic feedstocks and PtL



Key takeaways

- Estimated realistic 2030 SAF production from bio-feedstocks in Europe has increased from 1.9 Mt to 2.6 Mt in the past half year
- No plants have been announced with startup after 2027. As there will likely be additional announcements, it seems realistic that the EU and UK SAF mandates will be reached.
- SAF announcements are still pre-dominantly HVO/HEFA plants, which will use waste oils and fats. This is different in the UK, where the focus is less on HEFA but rather on MSW-based SAF.
- More and more oil companies are looking into possibilities to co-process oils/fats in existing refineries. We do not expect major SAF volumes from co-processing on the short term, however, given that:
  - Currently only up to 5% biogenic feedstock is allowed to be added to the fossil stream
  - Most of the biogenic molecules typically end up in heavier products such as diesel, which means that the biogenic content of the jet fuel is even lower than 5%
  - Not all jet fuel is produced in units that allow for co-processing
- It is unlikely that there will be PtL capacity before 2025, but several plants have been announced for the 2025 – 2027 period
- Most announcements target industrial point source as the CO_2 source, but the first commercial DAC plant has been announced

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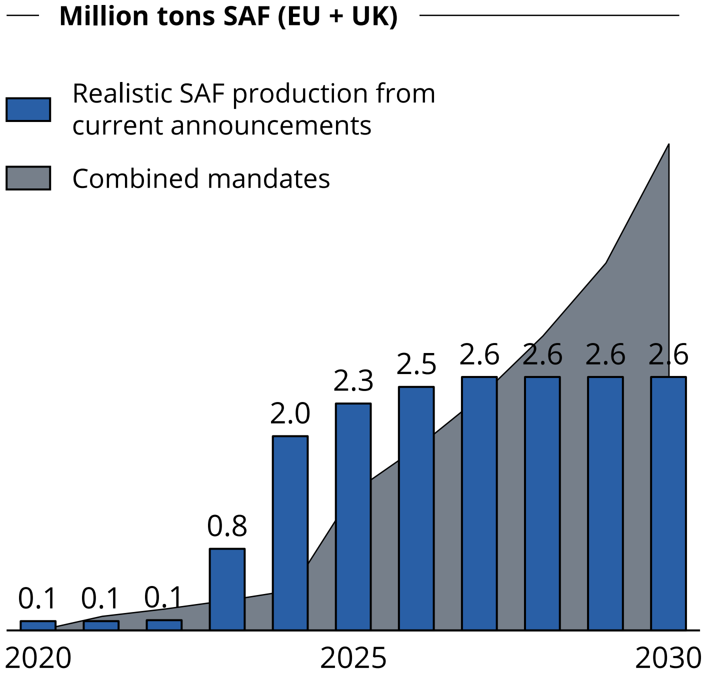
1A 1B 1C

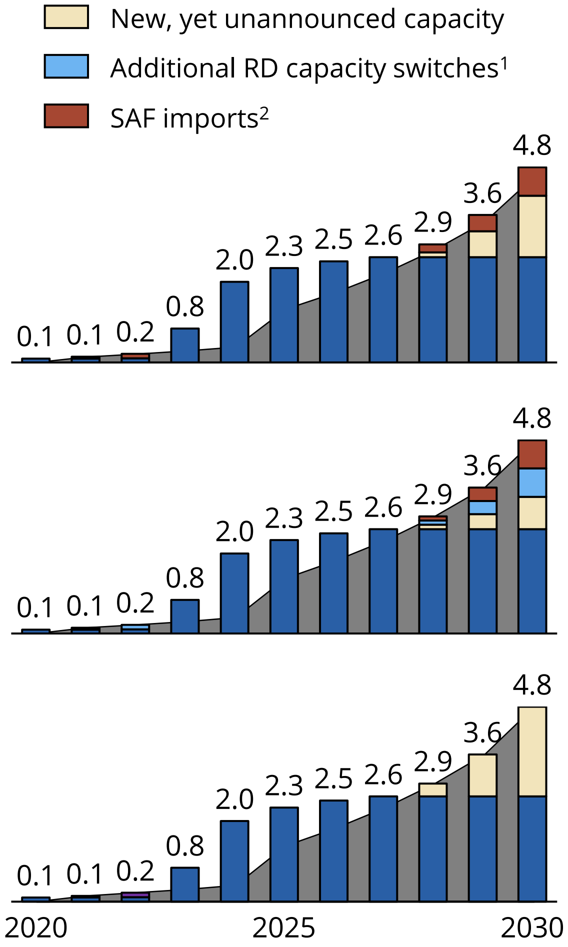
2

A combination of additional capacity, SAF imports and/or capacity switches from RD to SAF are required to close the gap

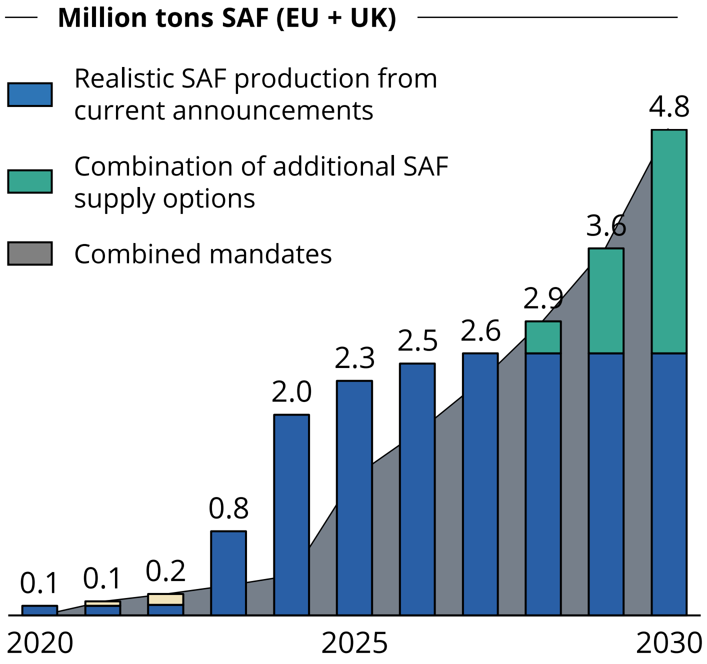
Realistic SAF supply scenario
(based on existing announcements and market constraints)



Various options possible to fill the gap



SAF supply scenario
(including options to fill the gap)



[1] *Potential for renewable diesel capacity to switch to SAF production is discussed in slide 11*
[2] *Potential for SAF imports from other regions is estimated at 2.2 Mt. See Appendix slide 34*

A multi-step approach is used to arrive at EU & UK SAF supply projections up to 2050

Step 1
2030 outlook

A

SAF supply from announcements

- Renewable fuel announcements (diesel/jet) are filtered to arrive at a 'realistic' SAF projection for 2030. We correct for:
  1. **a realistic SAF yield**;
  2. **projects that do not mention SAF;**
  3. **projects that are unlikely to materialize** (on time)

B

Feedstock/policy sense-checks

- We apply two further sense-checks to the realistic SAF scenario:
  - **policy**: assess demand for renewable fuels from road transport and marine to verify potential 'capacity switches'
  - **feedstock**: waste oil and fat availability when considering demand from other sectors

C

Closing the supply gap

- Potential for imports, new announcements and extra capacity switches is assessed
- We assume that all production that exceeds mandated demand is taken up by voluntary market or exported

Step 2
2050 outlook

- Few SAF plants are announced today that start after 2027
- To forecast SAF supply till 2050, we developed a capacity growth model, using tested metrics under the WEF Clean Skies for Tomorrow initiative which were chosen after thorough consultation with academics and industry
- Based on in-house knowledge and stakeholder engagement we enriched the analysis to create our own base case for EU & UK SAF supply
- Finally, we run a sensitivity analysis on to discover what are the most impactful drivers in this base case

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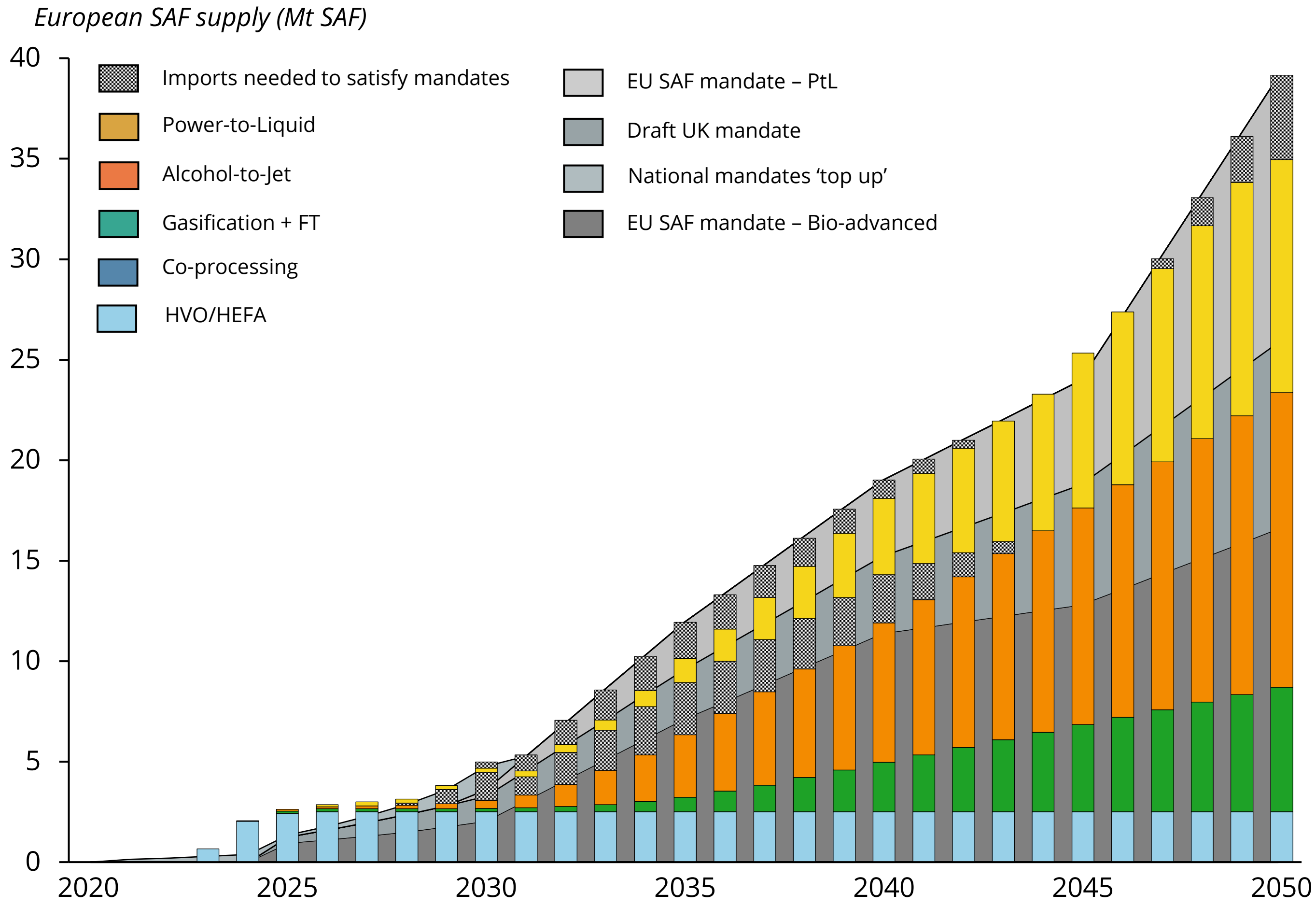
After 2030, SAF capacity increase in Europe will need to come from cellulosic waste and PtL



Key boundary conditions in this analysis

- Upscaling of plants is limited by global feedstock availability in case of HEFA, and EU feedstock availability for other pathways
- A maximum of 10 advanced biofuel plants are realized per year, with a maximum of 10 for PtL
- Imports amount to a maximum of 30% of the total SAF supply
- Product slates of FT and HEFA technologies are not fully jet-optimized due to expected fuel demand from road sector
- UK mandate assumed at same PtL/bio split as EU mandate
- See Methodological Annex for detailed methodology

Key takeaways

- About 400 SAF plants will be required to fulfil the expected European mandates by 2050 (vs. ~25 EU plants currently announced)
- Pathways depending on cellulosic (waste & residue) feedstock will become essential to achieving mandated volumes
- Rapid deployment of new technologies (FT, AtJ, PtL) and feedstock mobilization required to supply mandated volumes post 2030
- Imports are needed to achieve mandated volumes

Competing demand, technology development, feedstock supply and sector growth will dictate whether Europe ends up in market under- or oversupply

Market oversupply

Trends making a SAF oversupply situation more likely:

1. **Competing demand |** More rapid electrification of road transport freeing up biomass and production capacity for SAF production
2. **Feedstock availability |** Allowing new feedstocks under the RED II and mandate for bio-advanced SAF, or allowing e.g. recycled carbon fuels for the EU mandate
3. **Sector growth |** Aviation sector recovery limited: current projections assume jet fuel demand will recover to pre-covid volumes in 2024 and remains constant at 60 Mt after that
4. **Alternative aircraft |** More rapid developments in hydrogen/electric powered aircraft, reducing jet fuel demand and consequently absolute mandated SAF volumes
5. **Hydrogen sourcing |** Large-scale import of green hydrogen or allowing other types of hydrogen to be used for SAF production allow for a more rapid scaling of PtL capacity

To avoid oversupply, governments may increase blending targets or leave additional volumes for the voluntary SAF market

Market undersupply

Trends making a SAF undersupply situation more likely:

1. **Competing demand |** New or increased biofuel/biomass demand from other sectors, e.g. due to rising road sector mandates or incentives for marine and bio-chemicals
2. **Competing incentives |** SAF demand side stimulation outside EU, e.g. in US, Canada, China will put additional pressure on commodity feedstocks like waste and vegetable oils
3. **Sector growth |** Faster aviation sector growth: current projections assume jet fuel demand will recover to pre-covid volumes in 2024 and remains constant at 60 Mt after that
4. **Technology development |** Failure to widely commercialize and deploy technologies able to convert cellulosic biomass or CO_2 to SAF
5. **Policy |** As of January 2022, European Parliament is discussing a 100% SAF mandate by 2050. More stringent mandates could increase the risk of a market undersupply.

To avoid undersupply, governments may decrease blending targets or impose demand-side reduction mechanisms

3. United States SAF Outlook

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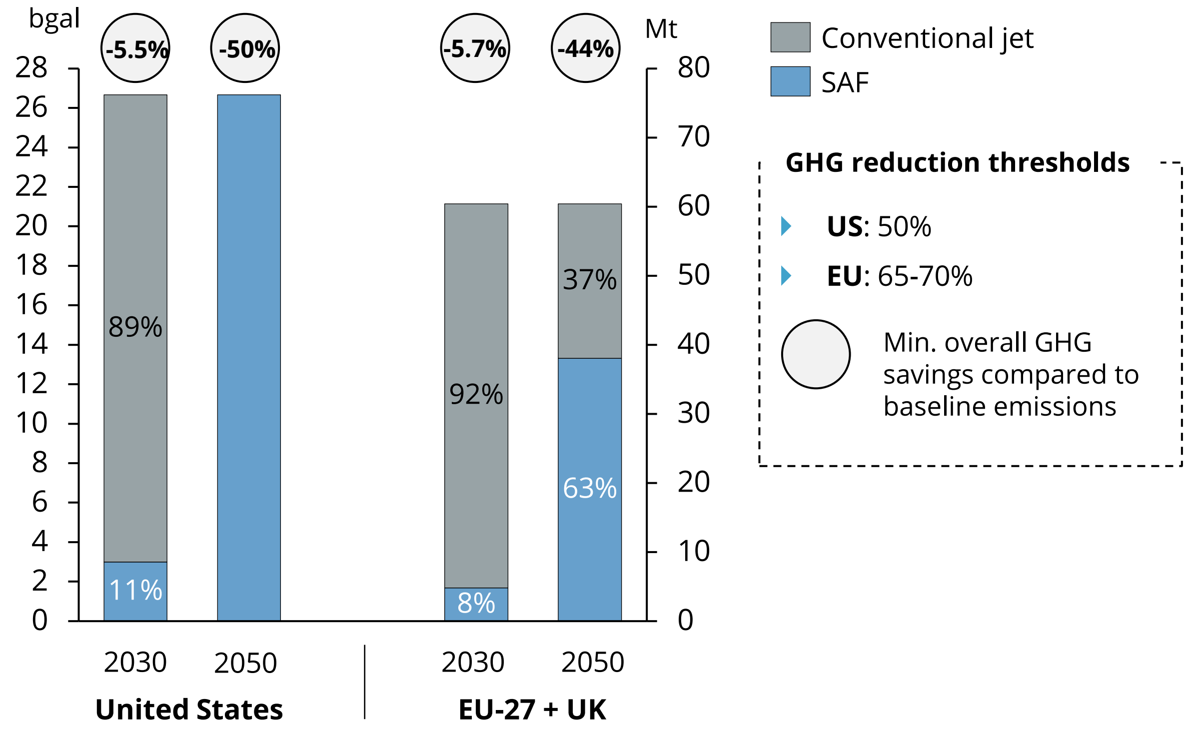
United States is pivoting into a global leader on SAF, with a new ambition of producing 3 billion gallons (~ 9 Mt) of SAF by 2030

2030/2050 jet fuel demand by type and GHG savings (bgal/Mt)



NB: Assuming 2030 jet fuel demand stays constant from pre-Covid levels; EU-27 + UK SAF volume includes more ambitious national mandates and the draft UK mandate

Source: based on average of 1.74 mbpd, EIA [link]

Key takeaways

- Under its *Sustainable Aviation Fuel Grand Challenge*, the United States is planning to increase production of SAF to 3 billion gallons by 2030.[1] This corresponds with roughly 16% of pre-Covid US jet fuel demand and close to double the expected volume in Europe.
- As the SAF Grand Challenge is a production goal, SAF imports are assumed to not play a role.
- Production in the US is expected to be driven by a SAF Tax Credit, which will lend its sustainability criteria from the Renewable Fuel Standard (RFS).
- A key eligibility criterion will be GHG savings, where SAF will have to achieve 50% GHG savings compared to conventional jet fuel. This is a lower threshold compared to the proposed mandates in Europe and brings overall GHG savings compared to baseline closer to that of the EU.
- Another key differentiator between Europe and the US is related to the eligible feedstocks:
  - the RFS in its current form allows the production of fuels from food/feed crops, like soy, canola and corn, which is not allowed under the mandates in Europe.
  - the RFS nor other incentives currently incentivize production of renewable fuels of non-biological origin, like Power-to-Liquids SAF, despite its vast potential.

[1] Source: *White House (2021)*

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A three-step approach is used to arrive at a US supply projection for 2030 and 2050

Step 1
2030 outlook

A Renewable fuel supply from announcements

- Renewable fuel announcements (diesel/jet) are scrutinized. We correct for projects that are unlikely to materialize (on time) based on:
  1. **a realistic SAF yield**;
  2. **projects that do not mention SAF;**
  3. **projects that are unlikely to materialize** (on time)

B Feedstock/policy sense-checks

- We apply two further sense-checks to this realistic renewable fuel scenario:
  - **policy**: assess demand for renewable fuels from low-carbon fuel policy in North America;
  - **feedstock**: assess feedstock availability for SAF when subtracting road demand

C Closing the supply gap

- Potential for new announcements is assessed on the basis of:
  - **eligible pathways** in the US;
  - **least-cost**;
  - **feedstock availability**;
  - **technology maturity**

Step 2
2050 outlook

- Few SAF plants are announced today that start after 2027
- To forecast SAF supply till 2050, we developed a capacity growth model for the European SAF sector, using tested metrics under the WEF Clean Skies for Tomorrow initiative which were chosen after thorough consultation with academics and industry
- Based on in-house knowledge and stakeholder engagement we adapted the European assessment to create our own base case for the US
- Most important changes compared to the EU methodology are related to the eligible food/feed crops in the US

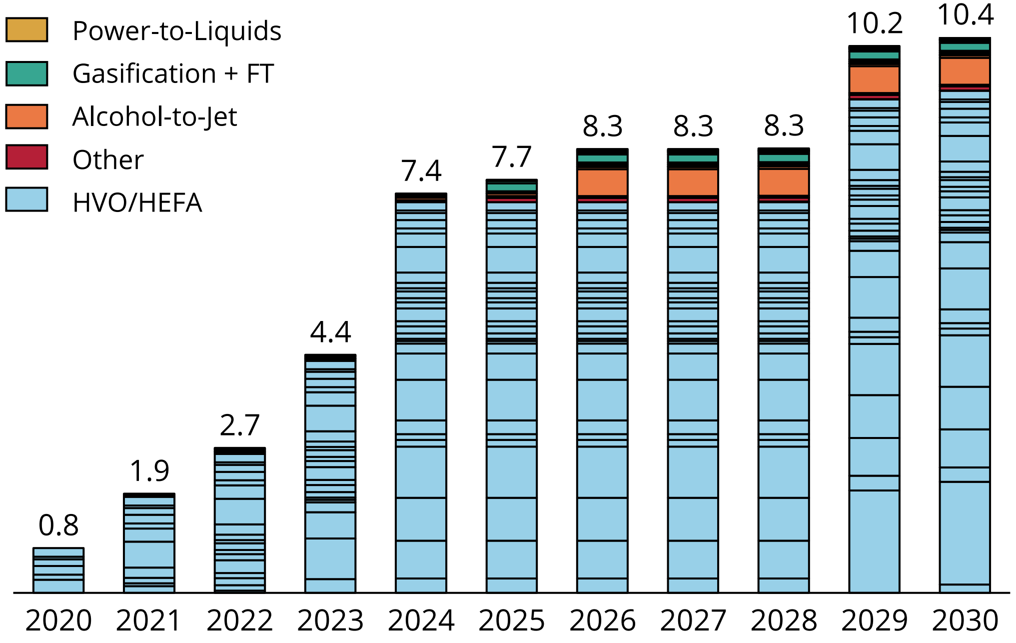
* Projects that are unlikely to materialize (on time) are excluded on the basis of: 1) meeting key project milestones; 2) updates provided in last two years; 3) proven track record vs. announced scale/feedstock

5.6 bgal (15.9 Mt) of renewable fuel projects expected to materialize in the US, predominantly HVO announcements

Step 1: Renewable fuel capacity

- To go from announced renewable fuel capacity to realistic SAF capacity in the US, SkyNRG reached out to project and technology developers. We correct for:
  1. **a realistic SAF yield**;
  2. **projects that do not mention SAF;**
  3. **projects that are unlikely to materialize*** (on time)

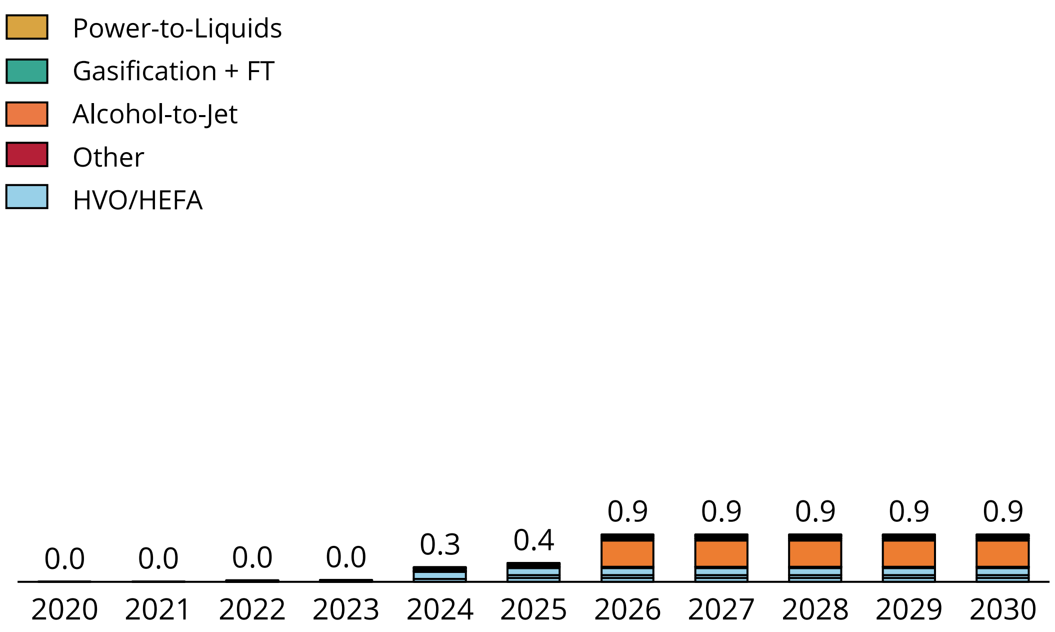
Billion gallons of renewable fuel



Step 2: Realistic SAF capacity

- Based on these filtering steps, we arrive at 0.9 bgal SAF capacity that is likely to materialize by 2026. There are no material SAF announcements beyond this date.
- When applying criterion 3 to renewable diesel announcements in the US, about **4.9 bgal** announcements remain (13.9 Mt). In the following section we assess whether these plants could switch to partially producing SAF.

Billion gallons of SAF



Based on having: 1) met key project milestones; 2) provided updated in last two years; 3) proven track record vs. announced scale/feedstock

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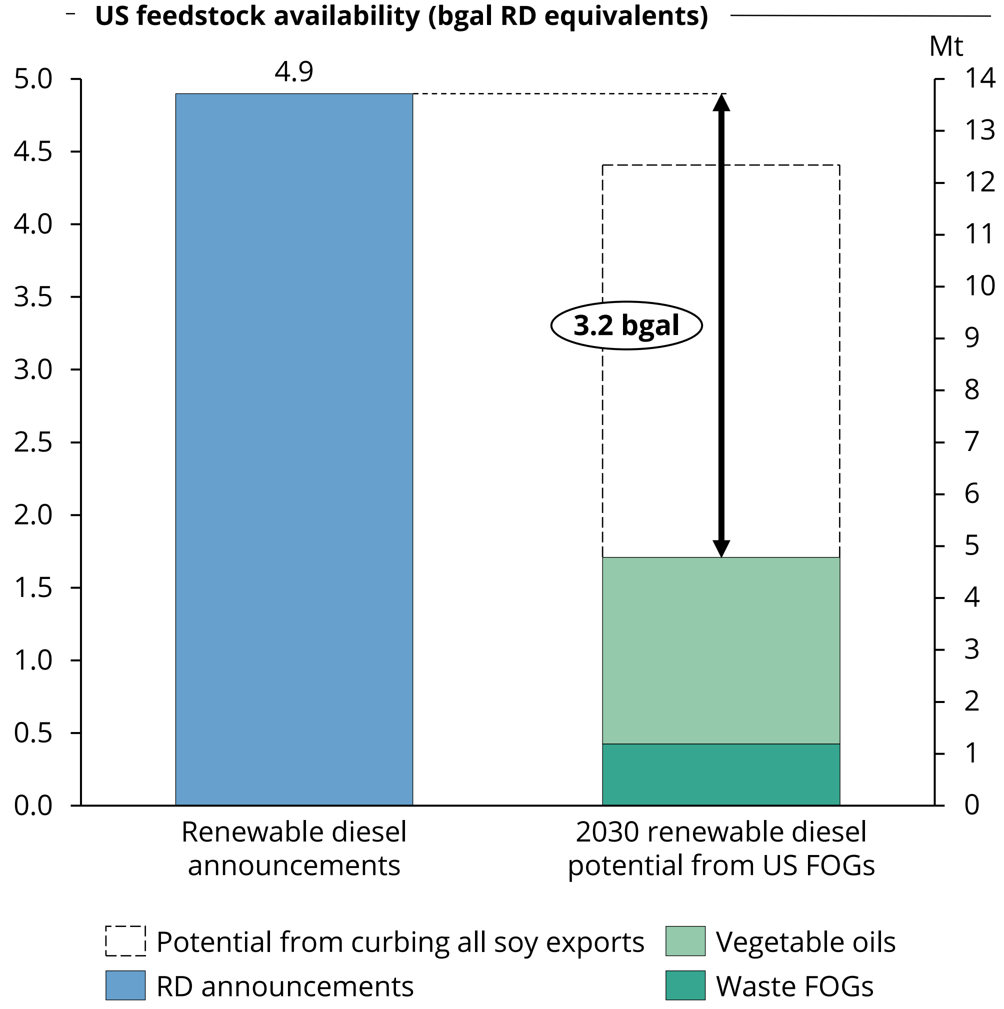
Feedstock check: US has highly constrained FOGs market; RD announcements will leave no feedstocks for SAF



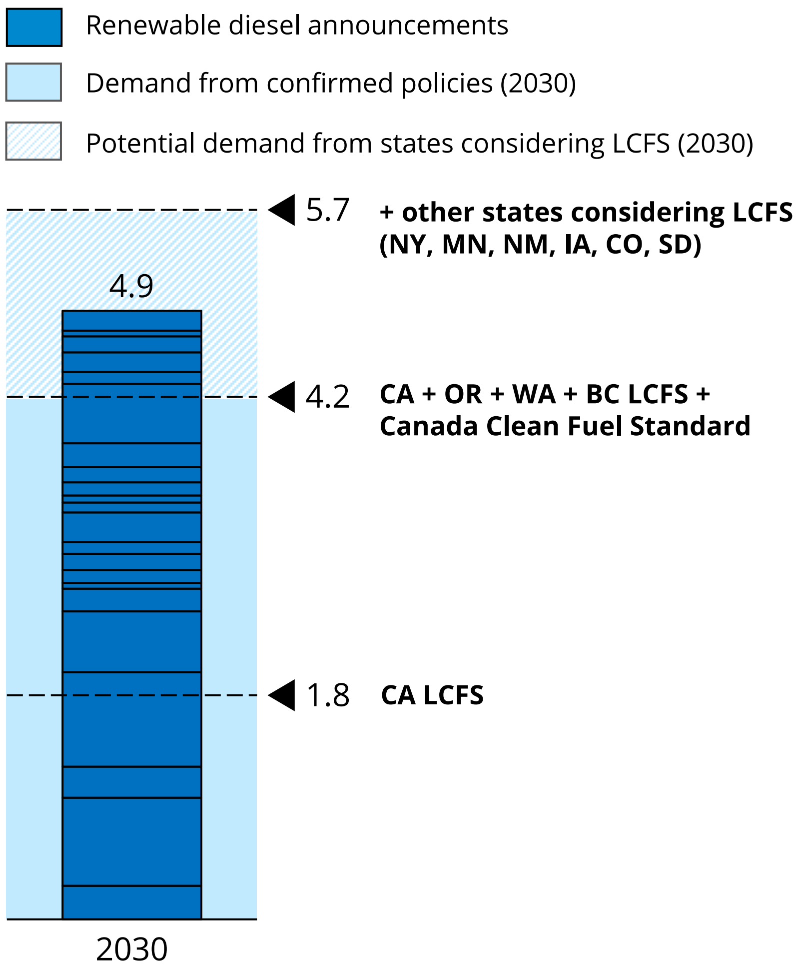
Key takeaways

- When all other end-uses of FOGs are subtracted from domestic production, about 14.5 billion lbs of FOG feedstock is available in the US by 2030,[1] this equals about 1.7 bgal (4.8 Mt) of renewable diesel.
- To meet the rising demand in biodiesel and renewable diesel from the RFS mandate and LCFS policies, 2020 demand for FOGs was already higher (17.5 billion lbs).[2]
- This means that any additional demand for biodiesel or RD beyond what is currently used must be imported or has to be displaced from other end-uses.
- Downsizing, cancelling of HVO announcements and/or feedstock diversion from FAME biodiesel plants therefore seems inevitable when comparing announcements with available feedstock in the US.
- For these reasons, the EPA already announced to not further expand the RFS diesel mandate, as increased use of these feedstocks ”will lead to diminishing incremental GHG benefits…”
- Due to the enormous pressure that will be exacerbated on the FOG market by these renewable diesel announcements**, we consider it highly unlikely that new announcements based on HEFA technology using domestic FOGs could materialize in the US**, unless they are supplied from imported feedstock.
- The net exporting balance of soy by the US is about 112 billion lbs (56 Mt). If this were all curbed towards domestic biofuel use and crushing capacity were developed, roughly 25 billion lbs (11 Mt) soy oil could be produced, enough for about 2.7 bgal (7.8 Mt) RD.[3] However, such a move could have a significant impact on the market price of soybean oil, making the pathway unattractive.

[1] Source: *ICCT (2020)*
[2] Assuming oil demand of 7.5 lbs/gal FAME biodiesel and 8.5 lbs/gal renewable diesel
[3] Source: OECD-FAO (2021), assuming 20% oil yield and 0.83% p.a. yield increase

Competing demand check: ~4.2 bgal RD capacity expected from confirmed policy in North America, little opportunity for capacity switches to SAF

RD announcements vs. confirmed policy (bgal RD)



[1] Source: *ICCT (2020)*

Key takeaways

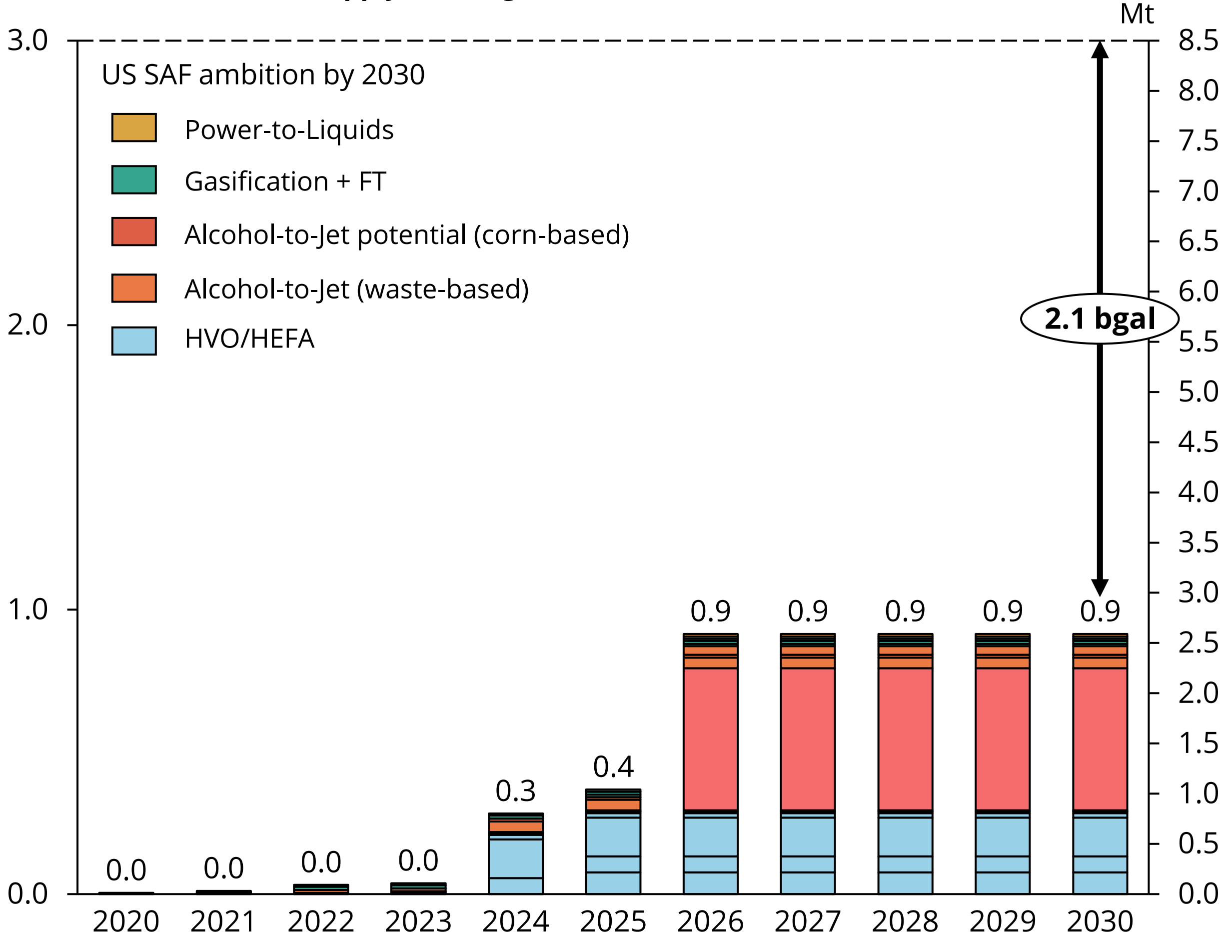
- Based on SkyNRG analysis (see previous slides), about 4.9 billion gallons of renewable diesel supply can be expected from currently announced projects that are considered likely to materialize.
- Based on confirmed low-carbon fuel policy, about 4.2 billion gallons of renewable diesel could find a home in North America, meaning there would be a slight oversupply of 0.7 bgal.
- Roughly half of these announcements lack pretreatment units, meaning they cannot take in the more contaminated animal fats and used cooking oils and would thus rely on inputs of clean vegetable oils.[1]
- If additional US states introduce LCFS policies, more demand for renewable diesel would be created than can currently be expected from RD announcements.
- Based on these cross-checks, we consider it likely that there is sufficient demand for renewable diesel to have these plants materialize. Any more announcements would produce for the export market.
- This also implies that there is little opportunity for capacity switches from renewable diesel to SAF, as this could create a shortfall of renewable diesel supply to meet North American low-carbon fuel policy demand.
- We therefore assume **no capacity switches from renewable diesel to SAF will materialize.**

[1] Source: *Argus* (2021)

SkyNRG

Realistic SAF supply in the US until 2030 is 0.9 bgal (2.6 Mt), this is 2.1 bgal (6 Mt) short of meeting the 2030 ambition

Realistic US SAF supply 2030 (bgal/Mt)



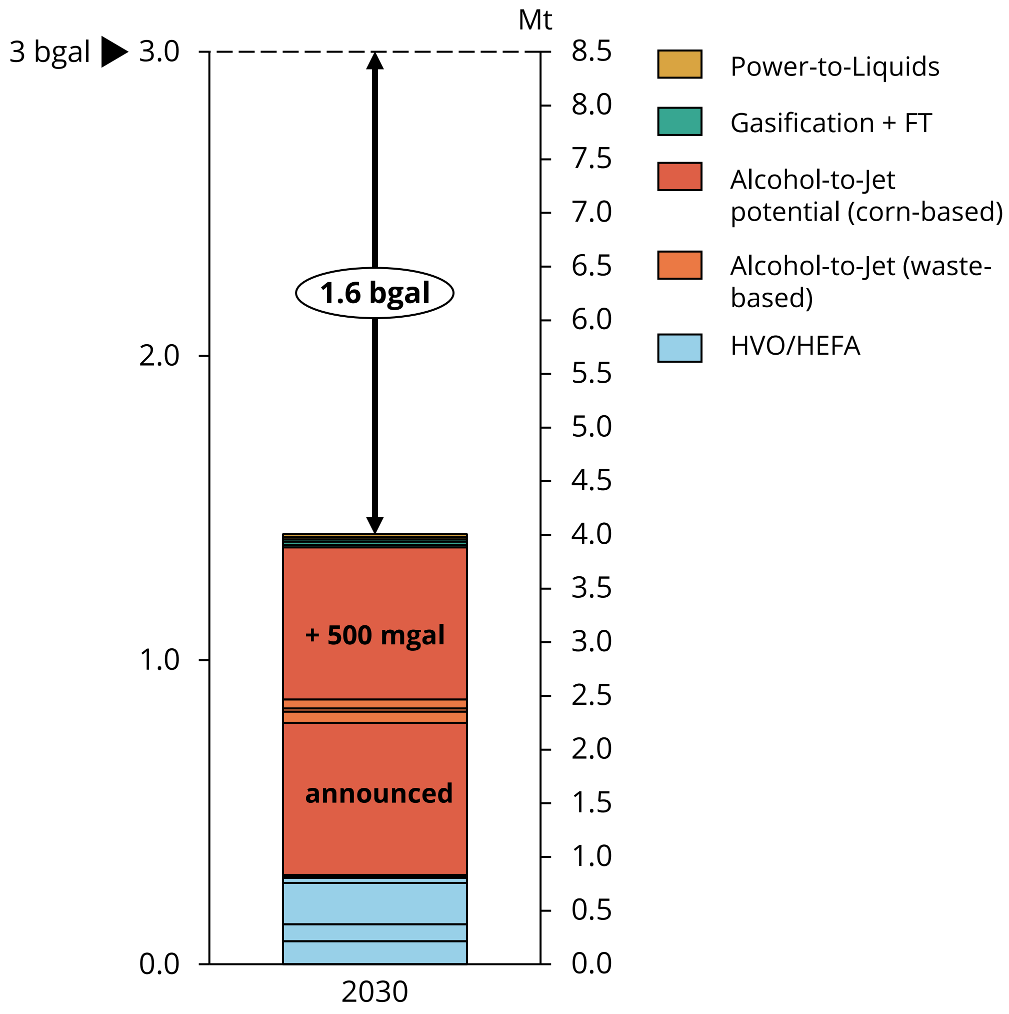
Assumptions

- Dedicated SAF capacity announcements and potential for renewable diesel capacity switches to SAF is included.
- US renewable fuel policies will remain as-is until 2030.

Key takeaways

- About 0.9 bgal (2.6 Mt) SAF can be expected by 2026–2030 with current industry announcements.
- This means the US is currently set to be about 2.1 bgal (6 Mt) short of meeting its 2030 SAF ambition of 3 bgal.
- The majority of this announced volume comes from one announcement to produce 500 mgal SAF from corn ethanol.
- Together with the vegetable oils that are projected to make up a large share of the HEFA feedstock, this means that the far majority of announced projects to date in the US will make use of food/feed inputs.
- The following section will assess the potential for additional SAF announcements and which feedstock-technology combinations are likely to fill the gap to 3 bgal SAF in 2030.

Corn ethanol ATJ could fill up to a third of the 2030 SAF target; tech. improvements needed to meet GHG criteria



Assumptions

- The US ethanol sector is currently in a situation of oversupply, driven by various factors:
  - EPA has frequently waived small refiners from complying with the RFS mandates, leading to a smaller market than anticipated by the sector.[1]
  - LCFS and RIN policies favor low-CI ethanol from Brazil, based on sugarcane/molasses.[2]
- This situation is unlikely to change towards 2030, as more stringent climate policies will stimulate electric driving and curb gasoline demand, eventually leading to a lower demand for fuel ethanol in the United States.[5]
- Although demand for ethanol in other countries could well rise strongly (e.g. from India's ethanol blending target), it seems likely that overcapacity is steered towards markets with the highest incentives.
- Average GHG savings of ethanol used under the LCFS in 2019 was 35% compared to gasoline.[3] Processing into jet fuel leads to additional emissions. Thus, to achieve a minimum of 50% GHG savings compared to fossil jet, significant on-farm GHG savings would have to be achieved, or at the ethanol plant (e.g. via CCS).

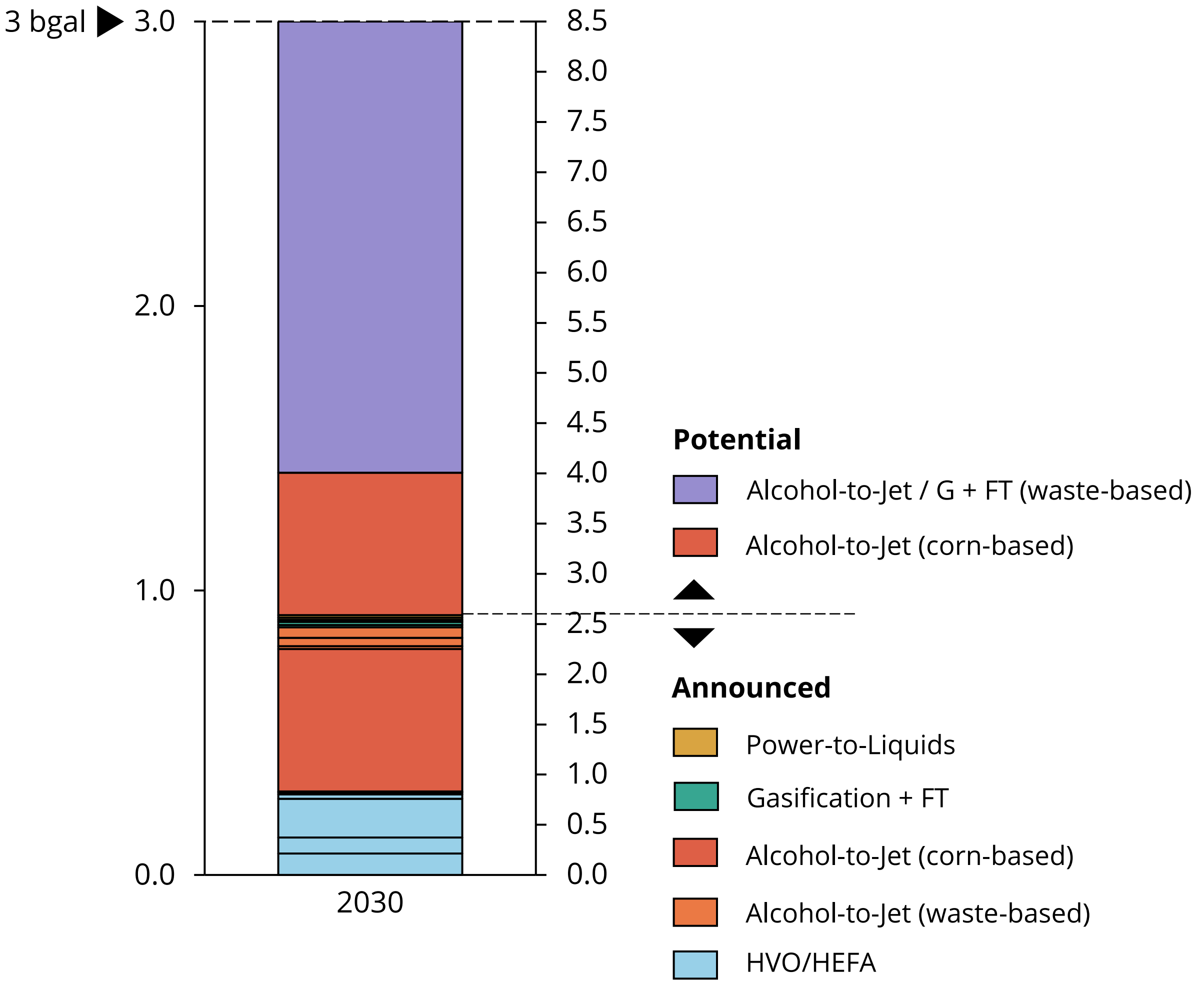
Key takeaways

- Based on the incentives corn-based SAF could enjoy in the US, combined the prospect of reduced fuel ethanol demand in the US by 2030, we estimate that at least 1.8 bgal of ethanol capacity could be steered towards SAF production, leading to **1 bgal of SAF capacity by 2030**.

[1] Argus (2021)
[2] Stratas Advisors (2020)
[3] USDA (2020)
[4] US BETO (2021)
[5] OECD-FAO (2021)

SkyNRG

Cellulosic waste and MSW will be needed to meet the US SAF target



Assumptions

- Technical SAF potential for waste-based AtJ/G+FT is **6–7 bgal** (17–21 Mt) SAF by 2030 (see Appendix for detailed assumptions).
- Given this significant technical potential, and correcting for demand from other sectors, we consider it possible that AtJ and G+FT pathways will be able to fill the remaining gap to reach the US SAF target by 2030 of **1.6 bgal** (3.1 Mt).

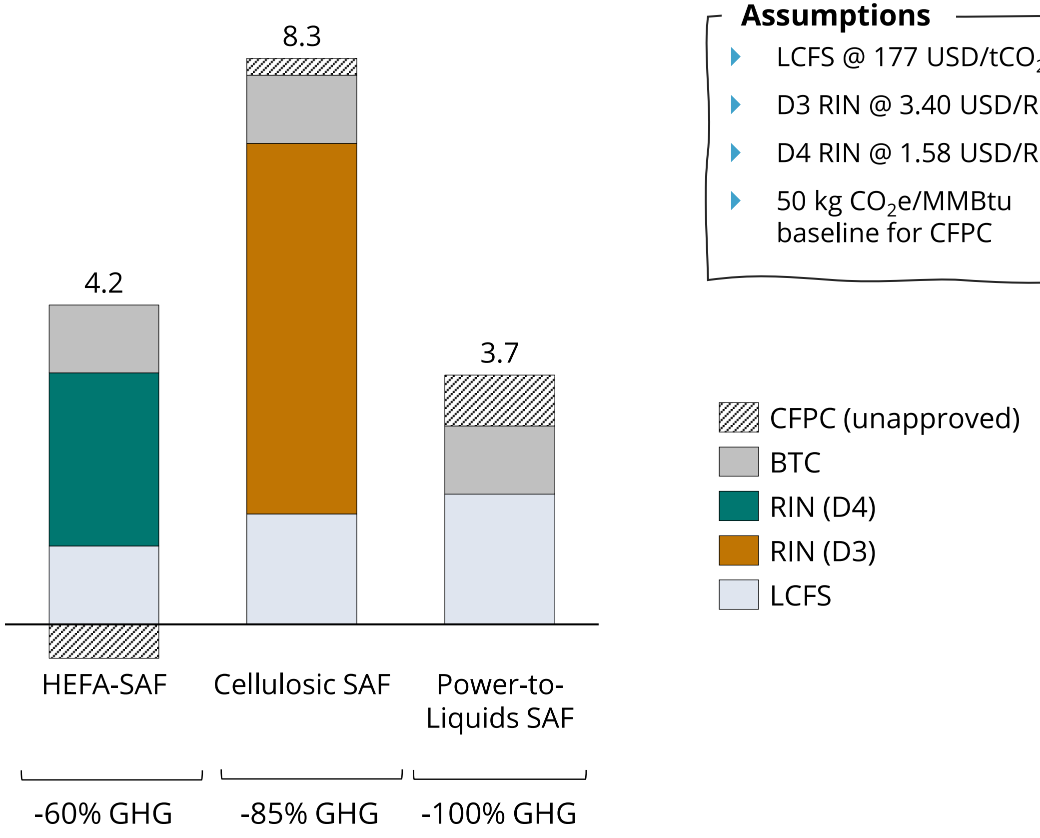
Key takeaways

- The pool of cellulosic waste and MSW feedstocks in the United States is enormous. If all were converted into SAF, supply could reach **14–18 bgal/y by 2040**.
- Given this huge potential and the incentives in place today, waste-based AtJ and G+FT are expected to close the 1.6 bgal gap to meet the target.
- This leaves Power-to-Liquids absent, despite having a significant potential (see next slide).

SkyNRG

Current low-carbon fuel policy in the US leaves significant untapped potential for PtL SAF

Stacked incentives for hypothetic SAF production scenarios (USD/gal fuel)



Assumptions

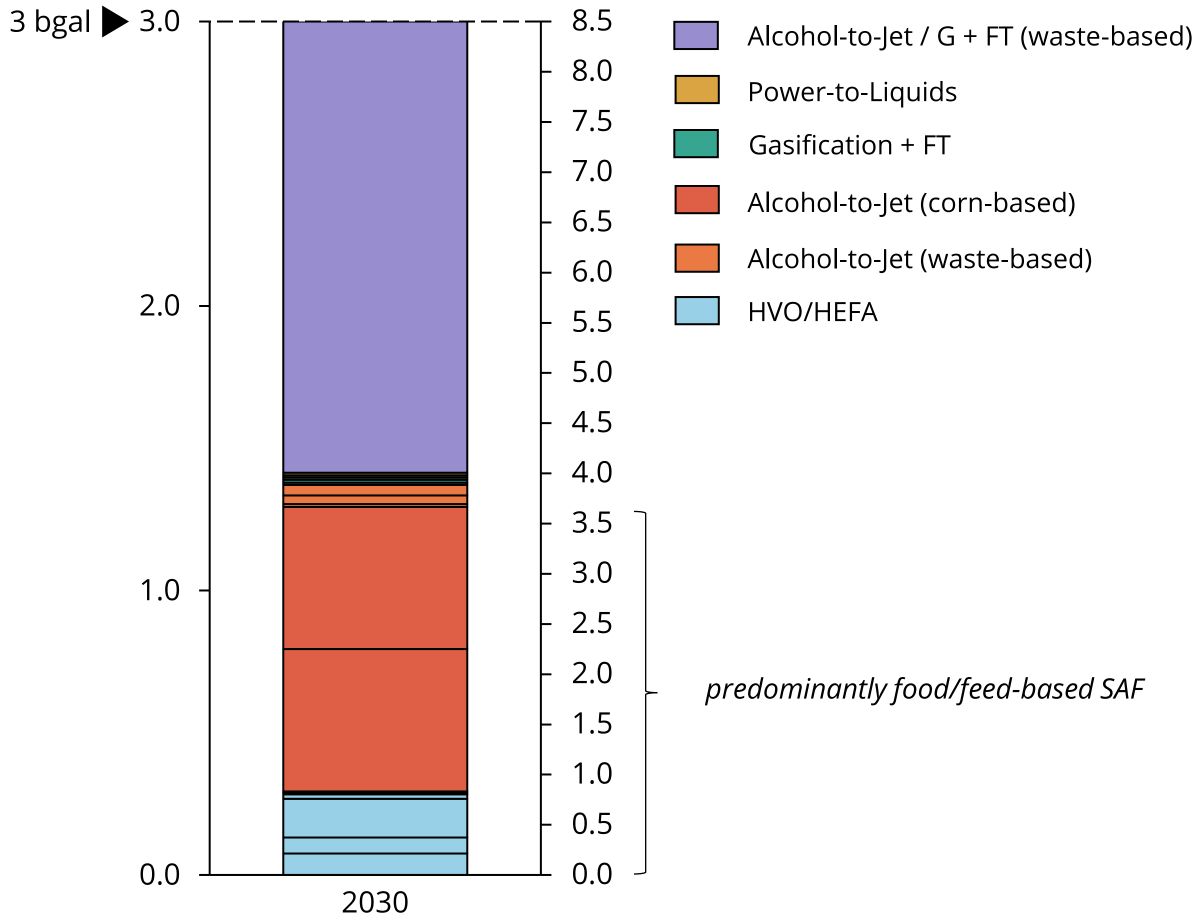
- LCFS @ 177 USD/tCO_2
- D3 RIN @ 3.40 USD/RIN
- D4 RIN @ 1.58 USD/RIN
- 50 kg CO_2e/MMBtu baseline for CFPC

Key takeaways

- Despite having vast renewable power resources that could be deployed to produce green hydrogen, there is very little PtL SAF capacity expected to be operational due to absent incentives in the US.
- The RFS does currently not incentivize non-biomass renewable fuels, leading to significant competitive disadvantage for PtL, which is more costly to produce compared to most bio-based routes.
- Because there is a PtL sub-mandate proposed in the EU, a business case could be made for US-based production oriented towards the EU market.
- This presents a missed opportunity, because the US Midwest has been shown to be a global hotspot for low-cost green hydrogen production, which could provide thousands of jobs for Midwest industrial workers.[1]
- NREL estimates a technical potential that far exceeds the jet fuel needs of the US. While other sectors will also demand green hydrogen, just 1% of the technical potential seems sufficient to fulfil US jet fuel demand.[2]
- **To increase the likelihood of achieving the US' 2050 SAF goals, incentives for PtL SAF would have to be developed** that would allow the private sector to tap into this huge potential.
- Mechanisms that have been discussed to stimulate such ultra-low CI fuels include:
  - Contracts for Difference
  - Aviation LCFS
  - Separate RFS mandate for hydrogen-based fuels in hard-to-abate transport sectors

[1] NRDC (2021)
[2] NREL (2020)

Close to half of all SAF under the 2030 ambition could be food/feed-based if sustainability criteria remain as-is



Conclusions 2030 Outlook

- With a production target of 3 bgal (8.5 Mt), the US is expected to have roughly double the SAF capacity compared to Europe by 2030.
- Based on eligible feedstocks in the US today, technology maturity and least-cost, we expect the US SAF target to be filled predominantly via the Alcohol-to-Jet and Gasification + FT pathways.
- HEFA route could displace AtJ/G+FT potential if feedstocks are diverted from renewable diesel to SAF production.
- Since the US has less stringent GHG thresholds and other sustainability criteria in place for renewable fuels, feedstocks are for a large part expected to be food/feed-based.
- Power-to-Liquids remains absent from the projected 2030 supply, due to the current policy framework not incentivizing renewable fuels of non-biological origin.

A three-step approach is used to arrive at a US supply projection for 2030 and 2050

Step 1
2030 outlook

A — Renewable fuel supply from announcements

- Renewable fuel announcements (diesel/jet) are scrutinized. We correct for projects that are unlikely to materialize (on time) based on:
  - **meeting key project milestones;**
  - **updates provided in last two years;**
  - **proven track record vs. announced scale/feedstock**

B — Feedstock/policy sense-checks

- We apply two further sense-checks to this realistic renewable fuel scenario:
  - **policy**: assess demand for renewable fuels from low-carbon fuel policy in North America;
  - **feedstock**: assess feedstock availability for SAF when subtracting road demand

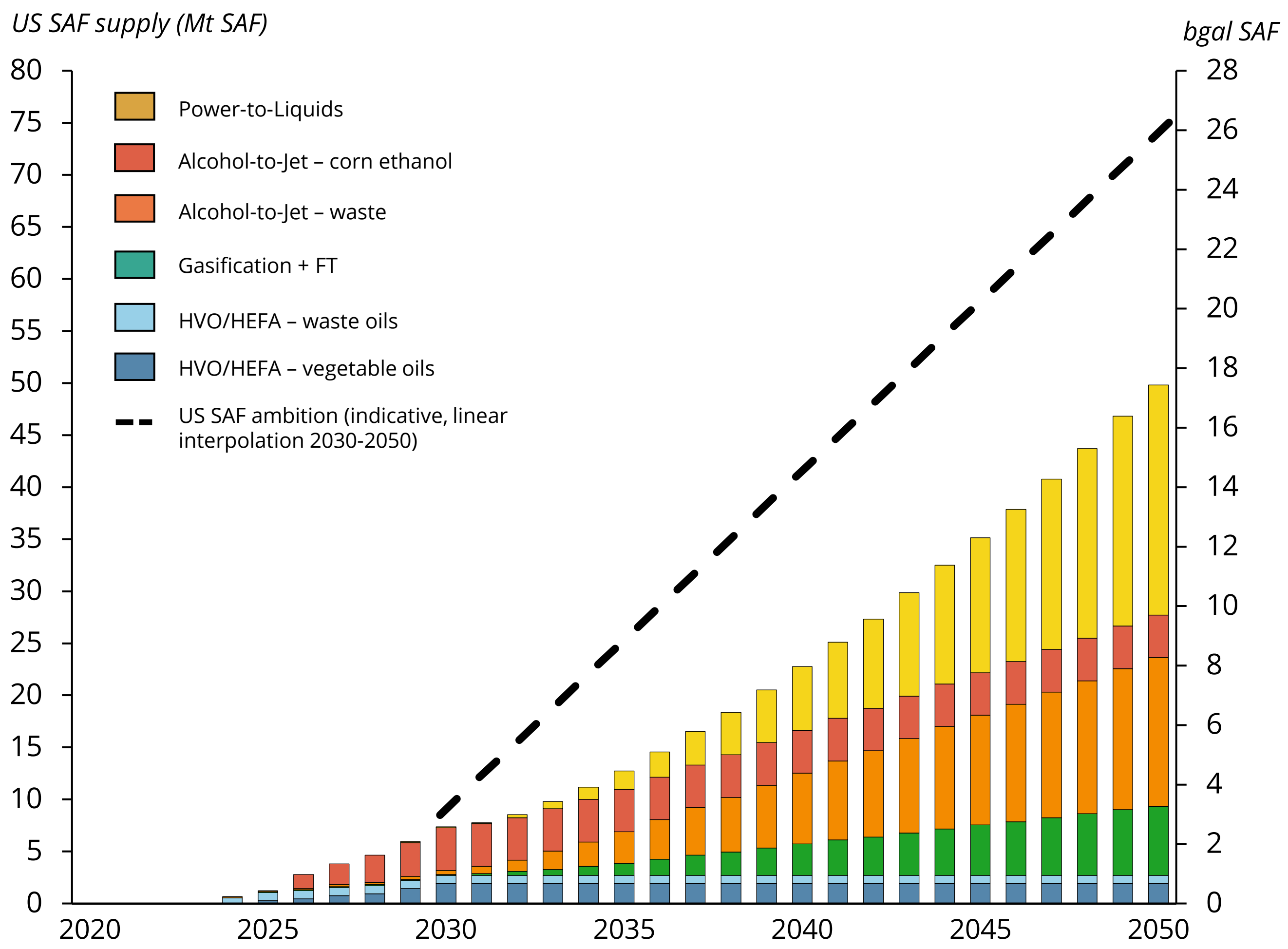
C — Closing the supply gap

- Potential for new announcements is assessed on the basis of:
  - **eligible pathways** in the US;
  - **least-cost**;
  - **feedstock availability**;
  - **technology maturity**

Step 2
2050 outlook

- Few SAF plants are announced today that start after 2027
- To forecast SAF supply till 2050, we developed a capacity growth model for the European SAF sector, using tested metrics under the WEF Clean Skies for Tomorrow initiative which were chosen after thorough consultation with academics and industry
- Based on in-house knowledge and stakeholder engagement we adapted the European assessment to create our own base case for the US
- Most important changes compared to the EU methodology are related to the eligible food/feed crops in the US

After 2030, SAF production increase in the US should mainly come from cellulosic waste and PtL



Key boundary conditions in this analysis

- Additional incentives are put in place for PtL and cellulosic SAF
- Deployment is limited by US feedstock availability for all pathways
- Max. 10 advanced biofuel plants per year, with a maximum of 20 for PtL
- Imports of SAF or intermediates do not contribute to the production goal
- Product slates of FT and HEFA technologies are not fully jet-optimized due to expected fuel demand from road sector
- Soy exports are curbed for domestic use; crushed into veg oil for SAF
- SAF target of 100% SAF by 2050 is linearly interpolated from 3 bgal in 2030
- See Methodological Annex for detailed methodology

Key takeaways

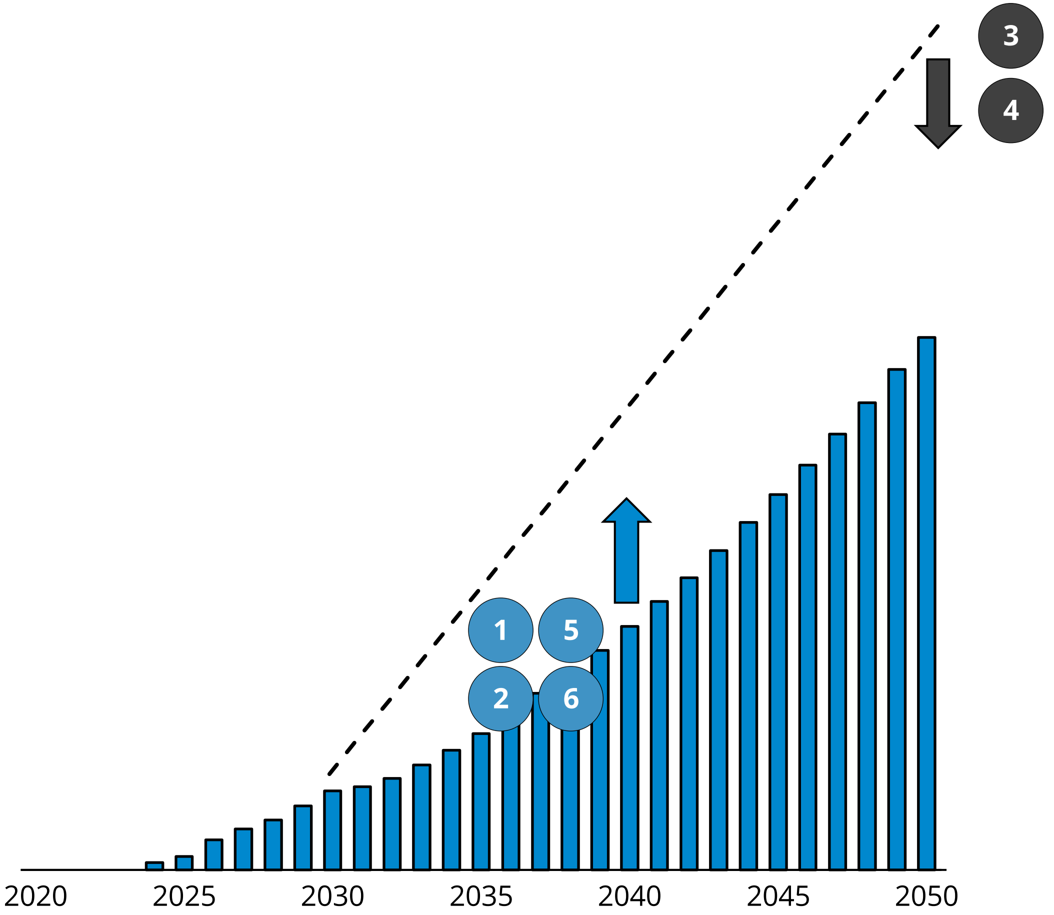
- About 750 SAF plants will be required to fulfil the expected US SAF ambition by 2050 (vs. ~15 dedicated plants currently announced)
- Pathways depending on cellulosic (waste & residue) feedstock and renewable power will become essential to achieving the SAF ambition
- Rapid deployment of new technologies (FT, AtJ, PtL) and feedstock mobilization required to meet 2050 target
- Even at ambitious deployment, potential SAF production in the US will not be sufficient to meet 100% of demand. Imports or demand-side measures will be needed to increase likelihood of meeting the target (see next slide)

We see a gap between SkyNRG's base case projection and the US SAF ambition – various drivers could change that picture

Drivers

Trends making the achievement of the US SAF target more likely:

1. **Competing demand |** More rapid electrification of road transport will free up biomass and production capacity for SAF production
2. **Feedstock availability |** Commercialization of new biomass supply chains, based on sustainable cover crops or oil-rich trees.
3. **Sector growth |** Current analysis assumes jet fuel demand will recover to pre-Covid volumes in 2024 and remain constant at ~27 bgal after that. Slower recovery would decrease the challenge; faster would do the opposite.
4. **Alternative aircraft |** More rapid developments in hydrogen/electric powered aircraft could reduce demand for hydrocarbon-based jet fuel by 2050.
5. **Imports|** Imports of intermediates/SAF are not included in the US analysis. Allowing imports of intermediates like ethanol or SAF could facilitate rapid increases in SAF blending, while decreasing energy independence.
6. **Incentives|** A more ambitious long-term framework for SAF investment, such as a dedicated (Federal) Aviation LCFS, could see more rapid deployment.



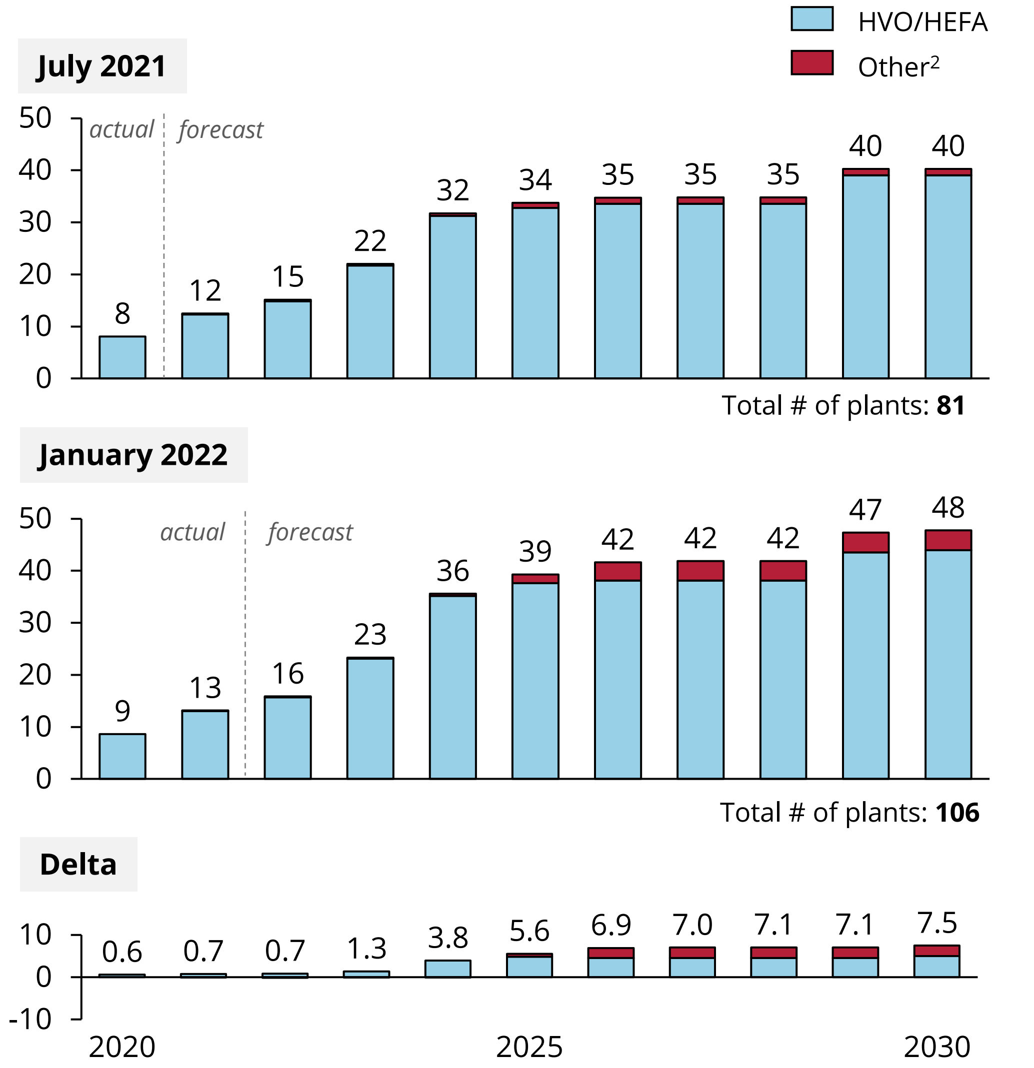
SkyNRG

4. Methodological Annex

SkyNRG

Since the previous outlook 6 months ago, global pipeline of renewable fuel projects has increased by 8 Mt in 2030, totaling 48 Mt of capacity

Global advanced renewable fuel[1] capacity outlook (Mt)



Changes in assumptions, inputs and visualization

- Besides having added new announcements, historical data was also changed. Most notably, some renewable diesel plants from China were added
- Additionally, due to updates from historical announcements, some production dates have been postponed

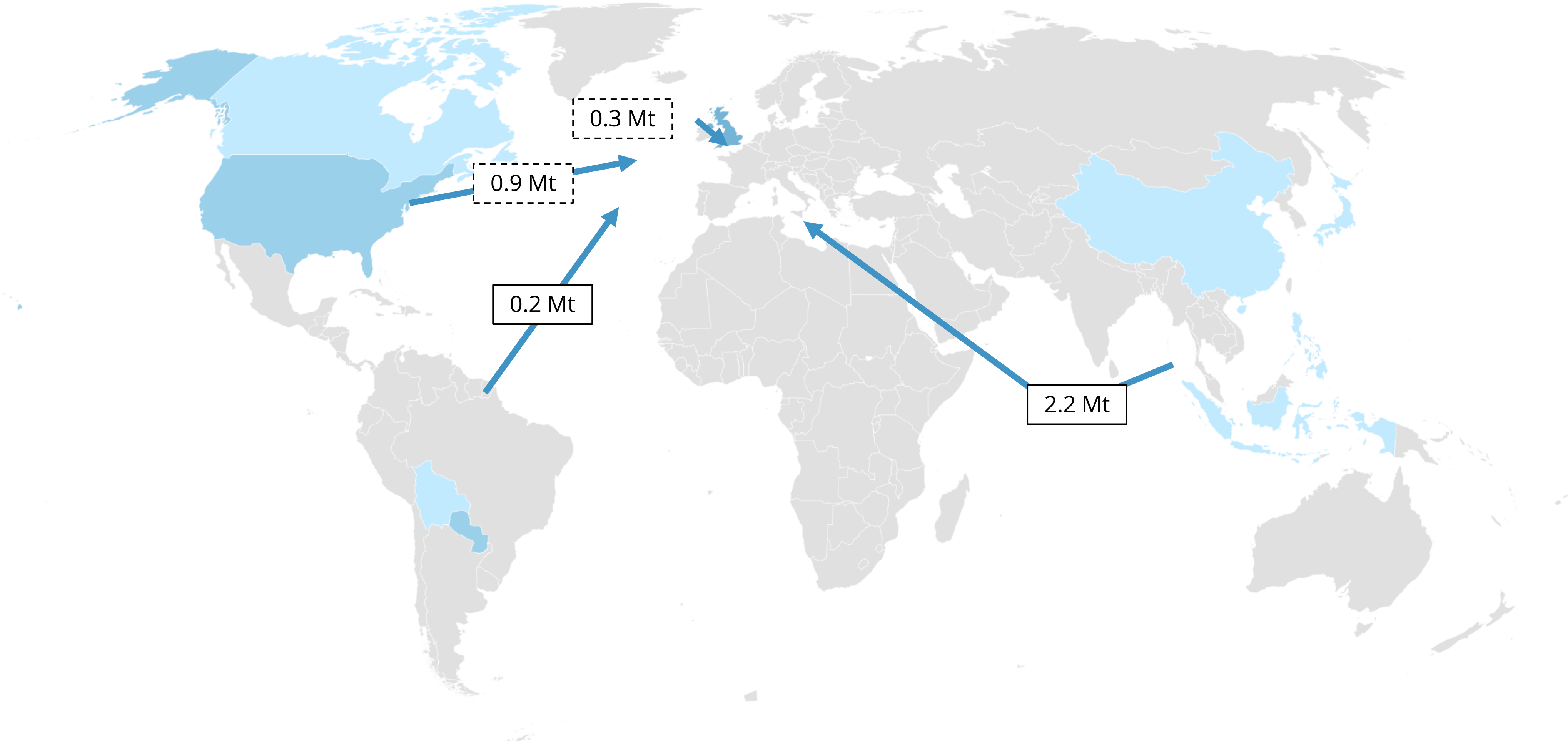
Key takeaways

- Renewable fuel announcements have accelerated in the past 6 months, which has led to an increase of the project pipeline by 8 Mt in 2030
- Most of these new announcements came from North America, where 5.5 Mt (1.9 bgal) of new capacity was added
- The share of projects making use of Alcohol-to-Jet and Gasification + Fischer Tropsch technologies has increased compared to the previous outlook

[1] Advanced renewable fuel is in this analysis defined as renewable diesel and SAF
[2] The 'Other' category consists of plants using any technology to produce renewable diesel or SAF besides HVO/HEFA

SkyNRG

SAF will increasingly become a global commodity – at least 2 Mt of SAF could come to the EU-27 based on announced projects

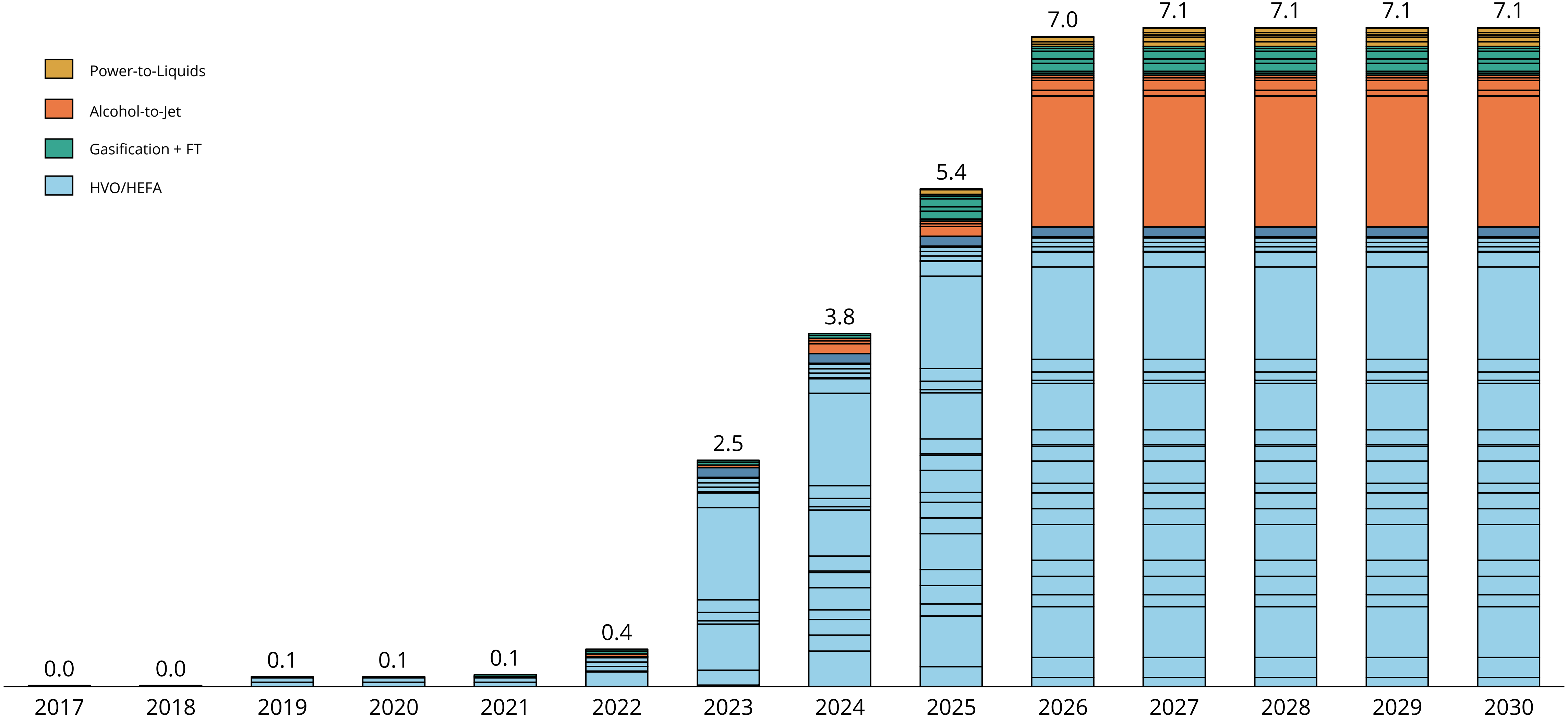


Region has a demand market for SAF

Region does not have a demand market for SAF

SkyNRG

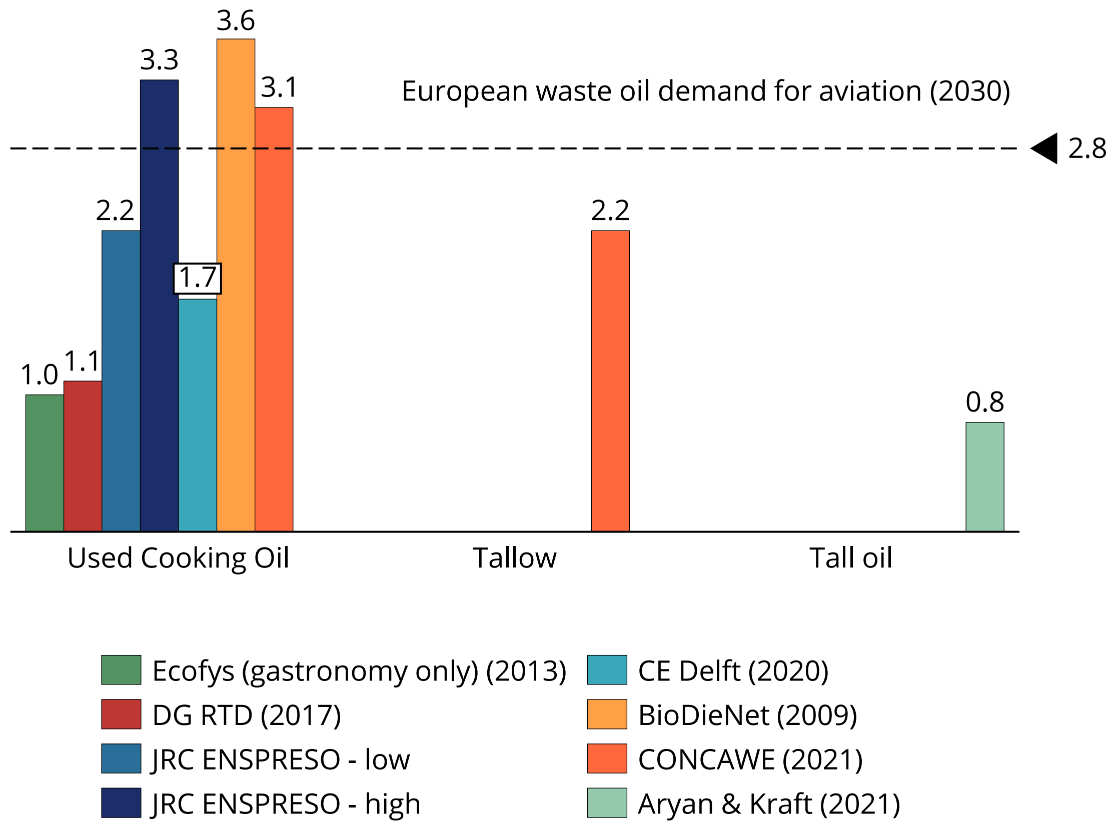
Based on realistic announcements only, global SAF supply is estimated at 7 Mt by 2026



SkyNRG

Based on European waste oil availability, aviation is set to take in roughly half of the supply based on projected capacity

European waste oil potential according to different studies (Mt)



Key takeaways

- Adding all the 2030 potentials for waste oil supply in Europe leads to a potential **of 4 – 6.6 Mt** waste oils.
- Currently, about 40–70% of UCO demand in Europe is imported from outside the continent (2.1–2.6 Mt). However, as other demand markets start to grow, mainly in the United States and Asia, the EU may have to rely more on domestic feedstock availability.
- Considering the demand for renewable diesel and FAME biodiesel in 2030 (15.6 – 25.3 Mt), it becomes obvious that non-waste feedstocks continue to be needed to produce renewable diesel and FAME biodiesel.
- Given the feedstock eligibility criteria in the ReFuelEU Aviation proposal, it seems likely that Annex IX-A and Annex IX-B feedstocks will be prioritized for aviation, whereas agricultural feedstocks can continue to be used in road and maritime to a certain extent.
- Currently, about 2.2 Mt of HVO/HEFA production capacity for aviation is expected to be online by 2030. This equals about 2.8 Mt of waste oil inputs or **45 – 70%** of all European waste oil supply potential by 2030.
- It seems urgent both from the perspective of energy security and sustainability that future announcements focus as much as possible on other feedstocks, like cellulosic residues, MSW and renewable electricity.
- This could be achieved by putting a larger emphasis in ReFuelEU Aviation on Annex IX-A feedstocks, e.g. by introducing an Annex IX-A sub-mandate in line with the RED II target of 0.5% in 2025 and 2.4% in 2030 or introducing a cap on Annex IX-B feedstocks.

SkyNRG

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Supply Analysis

Capacity Growth Model

I. Europe

A multi-step approach is used to arrive at EU & UK SAF supply projections up to 2050

Step 1
2030 outlook

A — SAF supply from announcements

- Renewable fuel announcements (diesel/jet) are filtered to arrive at a 'realistic' SAF projection for 2030. We correct for:
  1. **a realistic SAF yield**;
  2. **projects that do not mention SAF;**
  3. **projects that are unlikely to materialize** (on time)

B — Feedstock/policy sense-checks

- We apply two further sense-checks to the realistic SAF scenario:
  - **policy**: assess demand for renewable fuels from road transport and marine to verify potential 'capacity switches'
  - **feedstock**: waste oil and fat availability when considering demand from other sectors

C — Closing the supply gap

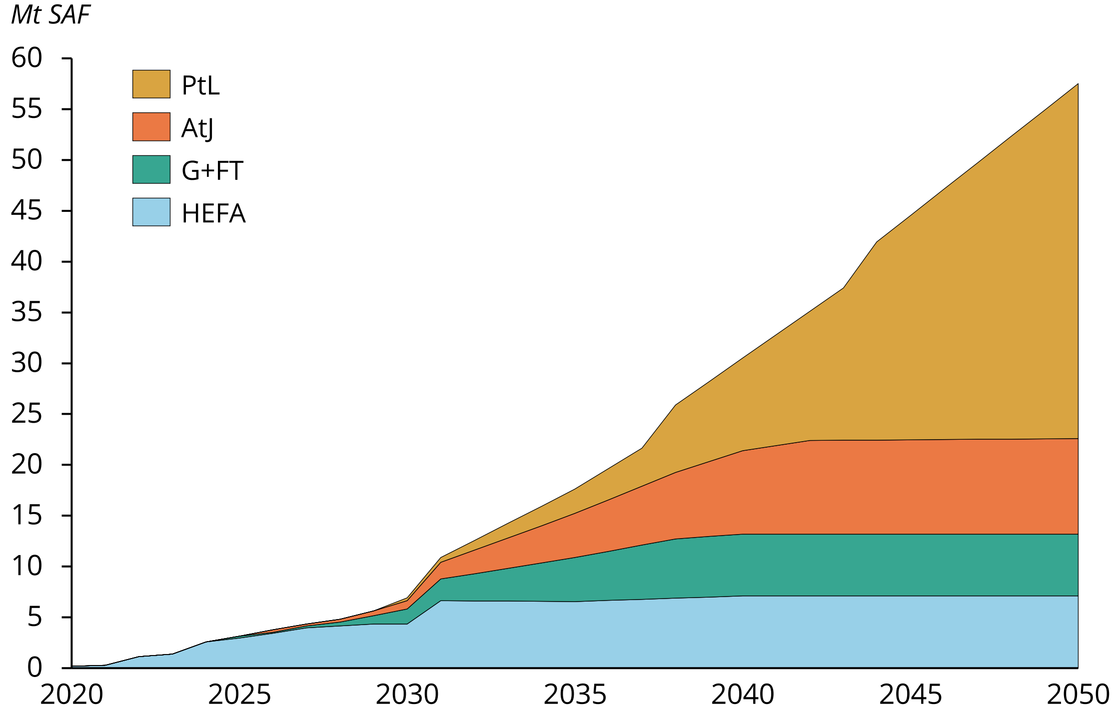
- Potential for imports, new announcements and extra capacity switches is assessed
- We assume that all production that exceeds mandated demand is taken up by voluntary market or exported

Step 2
2050 outlook

- Few SAF plants are announced today that start after 2027
- To forecast SAF supply till 2050, we developed a capacity growth model, using tested metrics under the WEF Clean Skies for Tomorrow initiative which were chosen after thorough consultation with academics and industry
- Based on in-house knowledge and stakeholder engagement we enriched the analysis to create our own base case for EU & UK SAF supply
- Finally, we run a sensitivity analysis on to discover what are the most impactful drivers in this base case

For the period 2028-2050, we estimate SAF supply taking the WEF CST model as basis, challenging assumptions and creating our own base case

- The WEF Clean Skies for Tomorrow analysis included 3 scenarios to model the potential SAF supply in Europe.[1]
- We rebuilt scenario 2, which assumes that there will be significant deployment of SAF capacity in Europe as a result of favorable policies and plants will optimize their output towards SAF, but no biomass is imported.
- The result of this rebuild, before any modifications, is shown in the figure on the right. The reasoning behind the modifications and results of this assessment are detailed in the next slides.

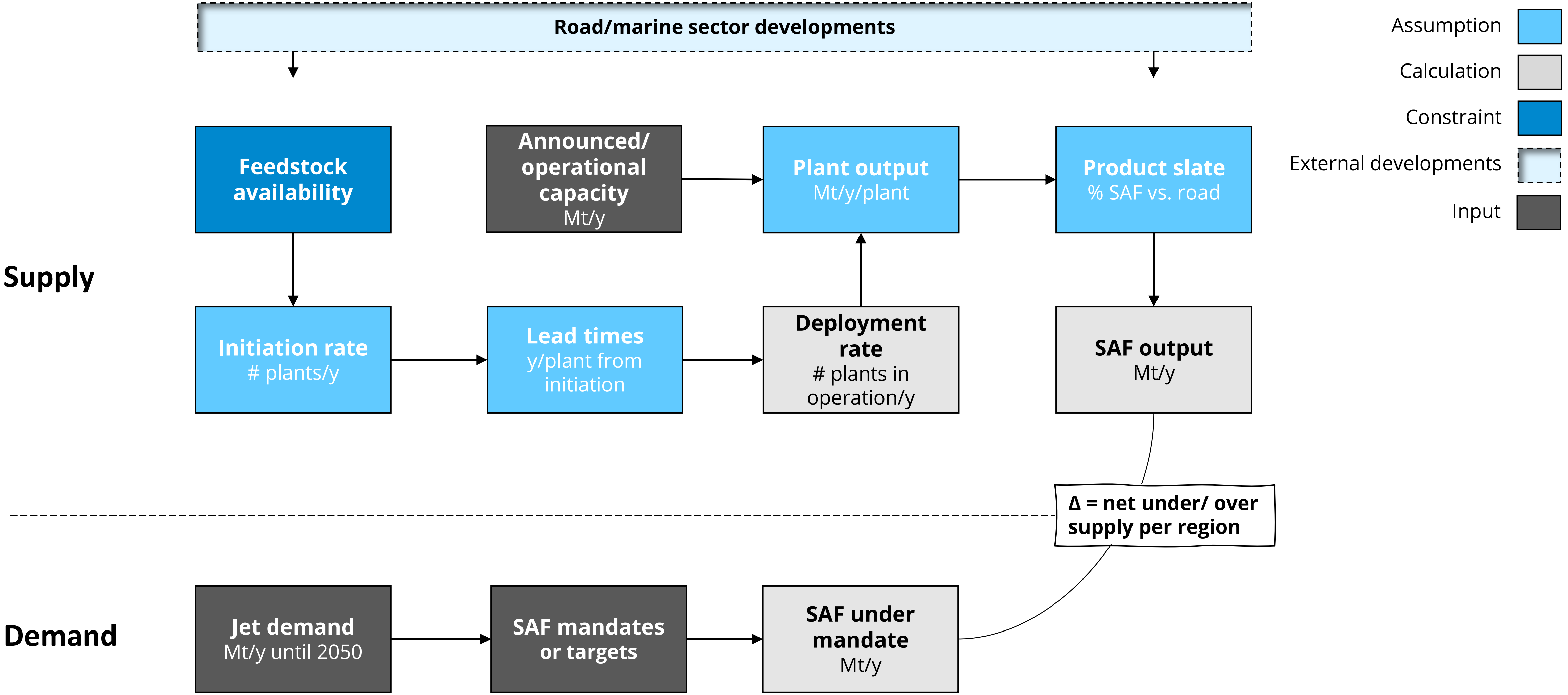


Total modelled SAF output, incl. announced plants, adapted from World Economic Forum Clean Skies for Tomorrow initiative. NB: aim of this study was to show the maximum potential supply of SAF as input to EU mandate discussions.

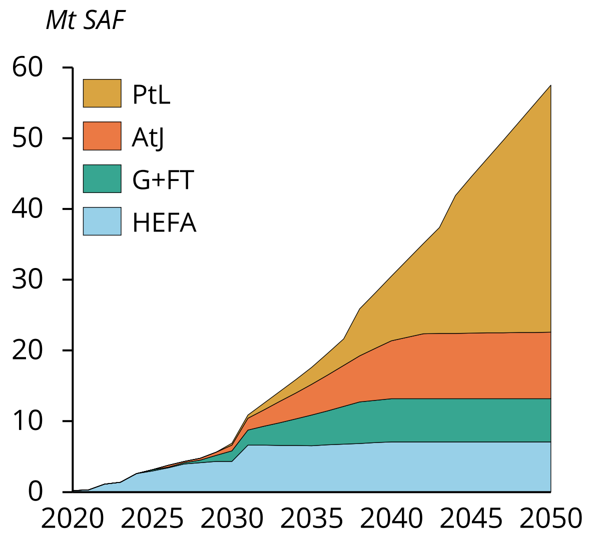
[1] *WEF CST, Guidelines for a Sustainable Aviation Fuel Blending Mandate in Europe, 2021 (link)*

SkyNRG

To be able to make our own base case, we developed a capacity growth model



SkyNRG reviewed WEF CST assumptions to arrive at a SkyNRG 'base case'



Impact on SAF production in base case

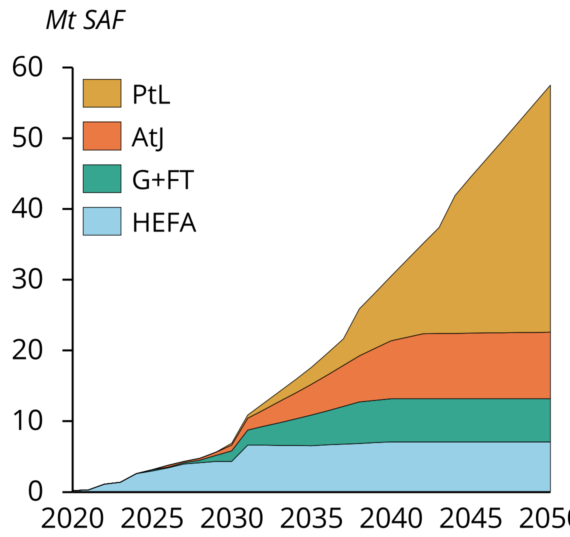
Longer reliance on existing technologies and slower uptake of new advanced pathways.

- The WEF scenario depicted on the left is *High deployment rate + jet optimized output*. The objective of this scenario in the WEF CST analysis was to demonstrate the potential SAF supply in the EU if everything falls into place. It is good to keep in mind that this is a very optimistic scenario.
- WEF CST also developed a 'low deployment scenario' which sees low initiation rates, but we are convinced this discussion merits an additional 'middle ground scenario' with the following assumptions relative to those made in WEF CST.

Scenario parameter	WEF CST assumptions[1]	SkyNRG reflection
Policy	Enabling policies will lead to rapid and sustained investment in SAF plants.	Valid assumption.
Success rate	All new planned projects to 2025 come to fruition and become operational on time.	In analyzing current SAF and HVO announcements, we observe that some plants have a lower chance of succeeding or ending up not producing SAF due to technology choices.
Product slates	All new and existing plants with the capacity to produce SAFs fully optimize output for jet fuel.	This seems unlikely, also in light of existing profitable business and obligations in road transport markets.
Plant initiation	New technologies overcome technical barriers within assumed project timelines. Advanced pathways start deployment around 2026/2027.	Advanced SAF production pathways are in general assumed to reach commercialization later compared to WEF, as today there are no sizeable advanced SAF plants online yet. If initiation happens when robust policies are in place, we can expect commercialization around 2030.
Feedstock supply	New biomass supply chains are developed to bring waste & residue feedstocks to SAF plants without logistical issues.	Valid assumption.
Feedstock allocation	40% of total biomass that is sustainably available in Europe is dedicated to jet fuel production.	Enthusiastic assumption. Not shared for HEFA and PtL, but difficult to substantiate counter arguments for AtJ and G+FT, so taken as is. See also page 25 for more details.

[1] *WEF CST, Guidelines for a Sustainable Aviation Fuel Blending Mandate in Europe, 2021 (link)*

Detailed assumptions for HEFA pathway in Europe until 2050



Impact on SAF production in base case

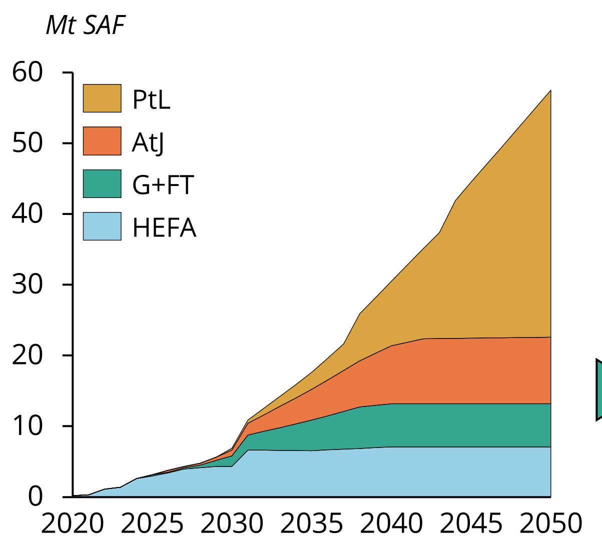
Fewer HEFA plants are initiated until 2025, when feedstock constraint is reached

Scenario parameter	WEF CST assumptions[1]	SkyNRG reflection (EU)
Feedstock availability	WEF assumes no imports. They take 20 Mt of oils and fats are available in Europe, and that 40% of this pool (i.e. 8 Mt) can be allocated to SAF in Europe. Breakdown: ▸ 2.4 Mt of waste oils and residues, includes used cooking oil, animal fat, fish oil, tall oil and other waste and residue lipids. ▸ 2.8 Mt of oil from oil trees on degraded land. 1% of the amount of degraded land is assumed to be practically available for oilseed bearing trees. ▸ 2.8 Mt of oil from oil-cover crops. It is assumed that 25% of the total amount of arable land is practically available for cover crops. This amount is allocated on a 20/80 division between oilseed bearing and cellulosic cover crops, respectively.	**Waste oils and fats** ▸ Currently, 60% of all waste oils processed for advanced fuel production in Europe are imported.[2] We therefore suggest an approach in which a maximum amount of the global pool of waste oils is allocated to SAF production in Europe → 3 Mt of waste oils for EU SAF production **Oil trees on degraded land** ▸ Currently, there is no indication that biomass from degraded lands will enter the RED-II definition of advanced fuel soon. We choose not to include these volumes **Cover crops** ▸ Currently being assessed for use as advanced biofuel feedstock under the RED-II. No existing (EU) supply chains. Mobilizing large quantities of these feedstocks in the short term seems unrealistic. We choose not to include the volume in the base case, but in the scenario analysis
Initiation rate	A low number of plants is initiated until 2025. After 2025 no plants are initiated due to feedstock constraints.	Due to tighter feedstock availability compared to WEF as elaborated above, a lower number of plants is announced until 2025, after which feedstock constraints are reached.
Lead time	3 years	Based on SkyNRG's experience with HEFA technology, we suggest to include an average lead time of 4 years from initiation until commercial operation.
Plant output	0.5 Mt middle distillate output	Not invalid assumption, although quite sizeable. This means 0.7 Mt feedstock input. Based on expert interviews, we assume a 50/50 split diesel/jet and a 70% conversion feedstock to jet, which yields 0.35 Mt feedstock for SAF and results in 0.25 Mt SAF output per plant.

[1] *WEF CST, Guidelines for a Sustainable Aviation Fuel Blending Mandate in Europe, 2021 (link)*
[2] *Greenea, Which investments will see the light in the biofuel industry?, 2021 (link)*

SkyNRG

Detailed assumptions for Gasification + Fischer-Tropsch pathway in Europe until 2050



Impact on SAF production in base case

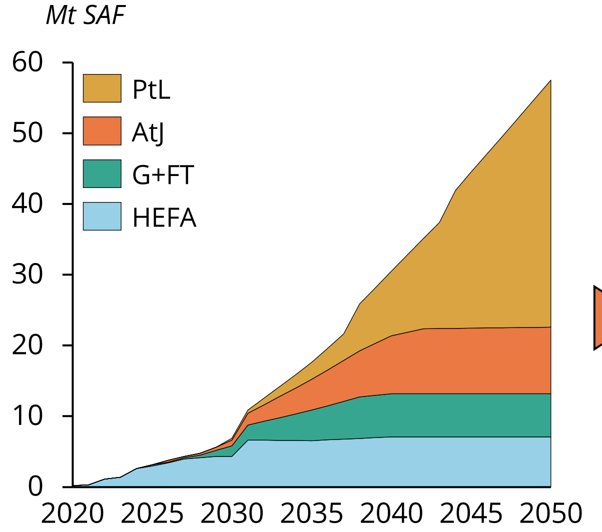
Slightly slower deployment due to lower SAF output per G+FT plant

Scenario parameter	WEF CST assumptions[1]	SkyNRG reflection (EU)
Feedstock availability	WEF assumes that 40% of a total of 640 Mt cellulosic material and MSW can be allocated to SAF production in Europe (i.e. 256 Mt). This feedstock pool is shared with AtJ and is broken down as follows: ▸ 36 Mt of cellulosic cover crops. Amount of arable land under temporary crops is based on FAOstat, 25% of this land is assumed to be practically available for cover crops; assumed split of 20/80 between oilseed bearing and cellulosic cover crops; ▸ 49 Mt of agricultural residues; ▸ 64 Mt of forestry residues; ▸ 41 Mt of wood-processing waste; ▸ 66 Mt of MSW. Availability is based on World Bank number for pure organic waste plus 20% of total plastic waste, assumed to be non-reusable.	▸ Cellulosic material will be in high demand in the coming decades for both the chemicals and (road) fuels sectors. This means that allocating 40% to SAF production is likely very optimistic. ▸ More realistic would be to assume a lower share, but at the same time also consider which feedstocks could be realistically imported to Europe. ▸ Regarding the individual potentials, there are also some remarks to be made. See page 36. ▸ All in all, we have insufficient robust analysis at the moment to assume different numbers compared to WEF, so more analysis on this feedstock pool is needed. ▸ We adopt the WEF numbers for the base-case
Initiation rate	Increases from 0 plants/year in 2020 to a maximum of 5 in 2028 and decreases again after 2035 due to feedstock constraints.	Valid assumption.
Lead time	6 years for a 1st commercial plant, 4 years for an nth commercial plant.	Valid assumption.
Plant output	0.15 Mt	Valid assumption.
Product slate	SAF is 60% of the total output pre-2030 and 70% post-2030	Through discussions between SkyNRG and FT technology developers, we could validate that these percentages are indeed the maximum SAF output for FT. Realistically however, based on project announcements and likely continuing incentives to produce renewable diesel, we assume a pre-2030 SAF output of 35% and post-2030 of 50%.

[1] *WEF CST, Guidelines for a Sustainable Aviation Fuel Blending Mandate in Europe, 2021 (link)*

SkyNRG

Detailed assumptions for Alcohol-to-Jet pathway in Europe until 2050



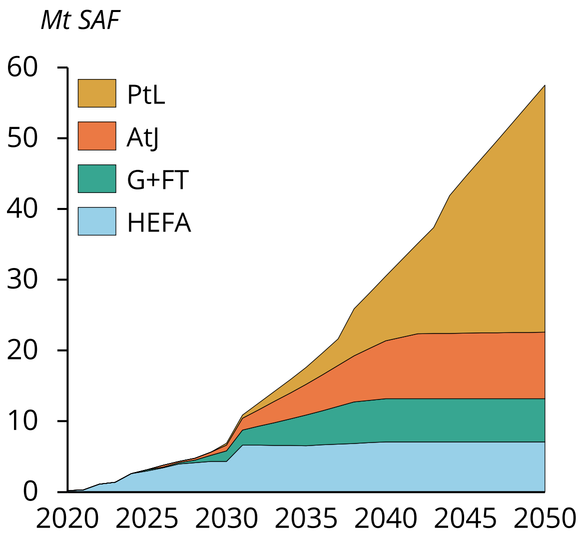
Impact on SAF production in base case

Slightly higher supply due to higher SAF output per plant

Scenario parameter	WEF CST assumptions[1]	SkyNRG reflection (EU)
Feedstock availability	Feedstock pool is shared 50/50 with G+FT, refer to previous page for assumptions and discussion.	WEF feedstock focus is 100% Europe, no imports. In the case of AtJ it is very likely there will be imports of (cellulosic) ethanol/alcohols, increasing the potential for deployment of this pathway in Europe
Initiation rate	Increases from 0 plants/year in 2023 to a maximum of 5 in 2031, and decreases again after 2038 due to feedstock constraints	Valid assumption.
Lead time	5 years for a 1st commercial plant, 4 years for an nth commercial plant.	Valid assumption.
Plant output	0.2 Mt	Operating in an integrated supply chain (including alcohol production) 0.2 Mt SAF/year is high, but not unrealistic. If an AtJ facility is operated in a hub-and-spoke supply chain where cellulosic ethanol is imported from other regions, up to 1 Mt/year is thought to be feasible. For our base case, however, we adopt the WEF assumption.
Product slate	SAF is 77% of the total output, both pre- and post-2030	Conservative assumption. Based on discussions and publications from technology providers we know that AtJ technologies are capable of producing a higher jet cut. We still take the WEF assumption for the base case, leaving upside potential in the scenarios

[1] *WEF CST, Guidelines for a Sustainable Aviation Fuel Blending Mandate in Europe, 2021 (link)*

Detailed assumptions for Power-to-Liquids pathway in Europe until 2050



Impact on SAF production in base case

Lower deployment, due to feedstock constraint and lower plant output

Scenario parameter	WEF CST assumptions[1]	SkyNRG reflection (EU)
Feedstock availability	No limitations included	Based on the projected amount of available renewable electricity in most of the EU's low-carbon 2050 scenarios, we believe including a constraint on which share of this amount can be used for SAF production would be realistic (i.e. 600 TWh). See page 25 for more detail
Initiation rate	Starts to ramp up after 2025 to 10 plants/year by 2045. Capped at 10 plants, compared to 5 plants/year for the other advanced routes in total.	Valid assumption, as the syngas production step requires different types of equipment compared to the advanced fuel routes. However, the FT step is also done in the Gasification route and might therefore face limitations in the supply chain. Also in reality, the initiation rate is constrained by the renewable power additions that can be done, which links to the maximum plant output as well.
Lead time	4 years	Valid assumption.
Plant output	0.4 Mt	Based on SkyNRG's discussions with technology providers, we estimate that a total plant output of 0.4 Mt would require a hydrogen input of about 164 thousand tonnes. To produce this amount of hydrogen, an installed renewable power capacity of about 2 GW offshore wind or 5.5 GW of solar PV in Spain are required. Especially in combination with the initiation rates assumed, this is considered unrealistic. We therefore suggest to set the maximum plant output at 0.2 Mt, while noting that this is already ambitious.
Product slate	Same as Gasification + FT	Same as Gasification + FT

[1] *WEF CST, Guidelines for a Sustainable Aviation Fuel Blending Mandate in Europe, 2021 (link)*

Additional details on feedstock assumptions for EU

Oils and fats

- We consider it more realistic to draw from the global feedstock pool of 40 Mt feedstock (McKinsey analysis).
- We consider that the EU can likely claim a maximum of a third of the global pool for all economic sectors by 2030, which it currently already does for UCO. This means the EU could claim about 13 Mt waste oil feedstock.
- In practice a significant share (at least 10 Mt) of the global waste oil potential will be already be required to satisfy EU road and marine transport targets.
- When we subtract this feedstock demand for road transport, we arrive at 3 Mt of waste oils and fats available to the EU SAF sector until 2030, which is more optimistic than the 2.4 Mt waste oils CST uses, but conservative compared to total 8 Mt oily feedstocks that are assumed.

- Mobilizing new biomass supply chains can take longer than 5 years, especially if it concerns feedstocks from species for which novel incentives have yet to be developed such as cover crops and oil trees on degraded land, or feedstocks that are not yet allowed under the RED II. While appreciating there is a significant upside potential, suggest to include this in our sensitivity analysis and not include these estimates in a realistic potential.

- Cover crops: see next box

Cellulosic & MSW feedstock

- WEF assumes that 25% of the total arable land can be used for cover cropping. Of which 20% will be then used for oil seed crops and 80% for energy crops.
- SkyNRG is currently not in a position to confirm or challenge this assumption.
- Based on current legislation, it seems appropriate to take the volumes along in the scenario analysis, not in the base case
- To get a better understanding of the actual potential of cover crops (oil & energy), we have started initial discussions with academics on this topic. SkyNRG will work to further validate this in the coming months.

- A sizeable part of the potential (33 Mt) comes from non-reusable plastic waste.
- Based on current legislation, it does not seem appropriate to take the volumes along in the base case nor the scenarios

- It seems realistic that certain primary feedstocks (e.g. wood pellets) or intermediates (e.g. ethanol) will be produced outside of Europe (close to feedstock source) and could be imported for processing into final SAF products in European facilities.
- It is included in the scenario analysis and SkyNRG will investigate this non-EU potential further in the coming months

Renewable electricity

- Although PtL SAF or the H_2 intermediate could well be imported from regions with better geographical conditions (i.e. cheaper renewable electricity), it is considered realistic to include a feedstock constraint for PtL production in the EU.
- The 35 Mt of PtL SAF assumed in this pathway would require a renewable power input of around 1100 TWh (only considering the power demand to produce the hydrogen), which represents around 30% of renewable power production assumed in most of the scenarios in the EU's 2050 low-carbon roadmap.[1]
- It seems unlikely that such a significant share of the EU's renewable power production would be allocated just to SAF production.
- We therefore suggest to include a constraint in line with the EU 2050 vision, where the power production allocated to PtL SAF production in their maximum technology scenario equals around 600 TWh. We include this constraint in our scenario.
- This results in lower amounts of PtL-SAF vs. WEF.

[1] *European Commission, A Clean Planet for all, 2018 (link)*

SkyNRG

II. United States

SkyNRG

A three-step approach is used to arrive at a US supply projection for 2030 and 2050

Step 1
2030 outlook

A Renewable fuel supply from announcements

- Renewable fuel announcements (diesel/jet) are scrutinized. We correct for projects that are unlikely to materialize (on time) based on:
  - **meeting key project milestones;**
  - **updates provided in last two years;**
  - **proven track record vs. announced scale/feedstock**

B Feedstock/policy sense-checks

- We apply two further sense-checks to this realistic renewable fuel scenario:
  - **policy**: assess demand for renewable fuels from low-carbon fuel policy in North America;
  - **feedstock**: assess feedstock availability for SAF when subtracting road demand

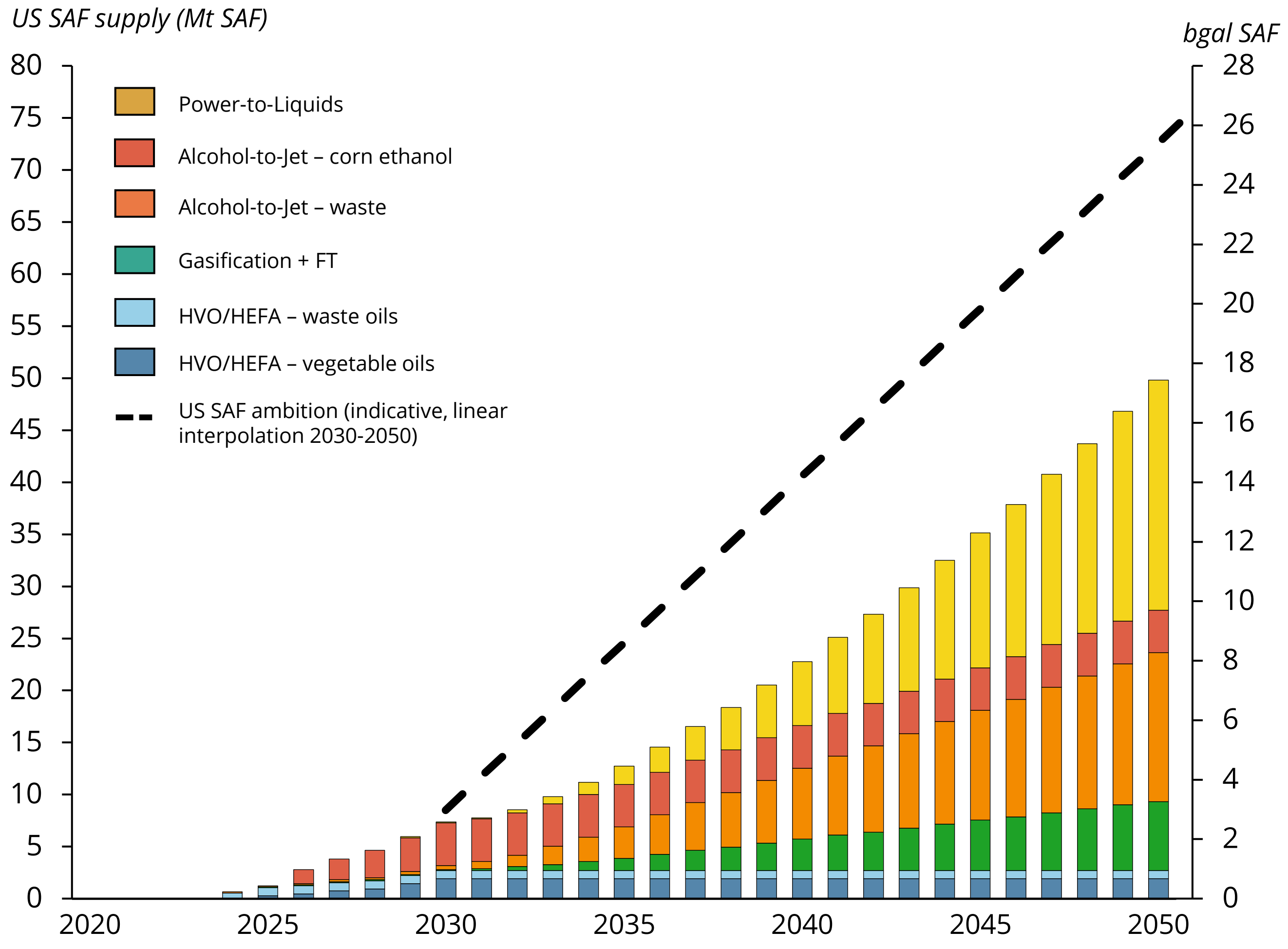
C Closing the supply gap

- Potential for new announcements is assessed on the basis of:
  - **eligible pathways** in the US;
  - **least-cost**;
  - **feedstock availability**;
  - **technology maturity**

Step 2
2050 outlook

- Few SAF plants are announced today that start after 2027
- To forecast SAF supply till 2050, we developed a capacity growth model for the European SAF sector, using tested metrics under the WEF Clean Skies for Tomorrow initiative which were chosen after thorough consultation with academics and industry
- Based on in-house knowledge and stakeholder engagement we adapted the European assessment to create our own base case for the US
- Most important changes compared to the EU methodology are related to the eligible food/feed crops in the US

SkyNRG base case for 2050 United States SAF supply



- See following slides for detailed assumptions.

SkyNRG

Detailed assumptions for HEFA pathway in the US until 2050

Scenario parameter	SkyNRG reflection (US)
Feedstock availability	**Waste oils and fats** ▸ Availability of waste oils and fats from domestic sources, according to the ICCT, is about 3.6 billion lbs, enough for roughly 400 mgal renewable diesel. Because renewable diesel announcements exceed 4 bgal it is expected that no feedstock will be left over for SAF. ▸ Taking a global lens does not change this picture much, since global availability is about 40 Mt (89 billion lbs). Assuming the US could claim a third of this would not be sufficient for the 16 Mt (36 billion lbs) feedstock demand from renewable diesel. **Vegetable oils** ▸ Availability of vegetable oils, correcting for other end-uses, is roughly 10.9 billion lbs, enough for 1.3 bgal renewable diesel. Same conclusion as for waste oils holds here too. ▸ However, the US currently exports significant amounts of soy (55 Mt). To illustrate this potential, we include a conversion of this soy to oil in the SAF supply, which amounts to roughly 11 Mt SAF. **Oil trees on degraded land** ▸ We choose not to include these volumes as no pilots have yielded commercial volumes to date. This might change as the prices for waste/vegetable oil increase. **Cover crops** ▸ No commercially viable supply chains exist yet. However, this could change as prices for waste/vegetable oil increase.
Initiation rate	We assume that the plants that have announced dedicated SAF capacity today will materialize, after which deployment will stop due to feedstock constraints. Veg oil-based plants continue to be deployed until 2030, after which we assume other SAF pathways will be more competitive as competition for oily feedstock will have significantly driven up prices.
Lead time	Based on SkyNRG's experience with HEFA technology, we suggest to include an average lead time of 4 years from initiation until commercial operation.
Plant output	0.5 Mt (180 mgal) output per facility. Based on expert interviews, we assume a 50/50 split diesel/jet and a 70% conversion of feedstock to jet, which yields 0.35 Mt feedstock for SAF and results in 0.25 Mt SAF output per plant.

SkyNRG

Detailed assumptions for Gasification + Fischer-Tropsch pathway in the US until 2050

Scenario parameter	SkyNRG reflection (US)
Feedstock availability	The feedstock pool for G+FT is shared with AtJ and it is assumed that 40% of the feedstock can be allocated to use in aviation, in line with the assumption under WEF CST. The pool adds up to a total of 477 Mt and is broken down as follows, based on McKinsey analysis: ▸ 45 Mt of cellulosic cover crops. Amount of arable land under temporary crops is based on FAOstat, 25% of this land is assumed to be practically available for cover crops; assumed split of 20/80 between oilseed bearing and cellulosic cover crops; ▸ 117 Mt of agricultural residues; ▸ 184 Mt of forestry residues; ▸ 109 Mt of wood-processing waste; ▸ 67 Mt of MSW. Availability is based on World Bank number for pure organic waste plus 20% of total plastic waste, assumed to be non-reusable. ▸ Cross-checks with the EPA's billion-ton study (2016) yield figures that are in the same order of magnitude: 389 – 448 Mt for waste cellulosics, vs. a 477 Mt total from McKinsey. Only the estimate for cover crops is significantly higher at 547 – 853 Mt. ▸ Cellulosic material will be in high demand in the coming decades for both the chemicals and to a lesser extent also the road/maritime sectors. This means that allocating 40% to SAF production could be optimistic. ▸ Given the potential upside for cellulosic cover crops, we maintain the 40% assumption on the McKinsey estimates.
Initiation rate	▸ Increases from 0 plants/year in 2020 to a maximum of 5 in 2030 and stays constant until 2050. ▸ Feedstock constraint is not reached.
Lead time	6 years for a 1st commercial plant, 4 years for an nth commercial plant.
Plant output	0.15 Mt (~50 mgal)
Product slate	▸ SAF is 60% of the total output pre-2030 and 70% post-2030 ▸ Through discussions between SkyNRG and FT technology developers, we could validate that these percentages are indeed the maximum SAF output for FT. Realistically however, based on project announcements and likely continuing incentives to produce renewable diesel, we assume a pre-2030 SAF output of 35% and post-2030 of 50%.

SkyNRG

Detailed assumptions for Alcohol-to-Jet pathway in the US until 2050

Scenario parameter	We reflection
Feedstock availability	▸ Same feedstock pool as G+FT is assumed for waste and cover crop feedstocks. However, in the US food/feed crops need to be considered for the AtJ pathway. **Corn ethanol** ▸ The US ethanol sector is currently in a situation of oversupply, driven by various factors. ▸ This situation is unlikely to change towards 2030. President Biden announced that by 2030 he wants 50% of all cars and trucks sold to be electric, which will curb gasoline demand, eventually leading to a lower demand for bioethanol in the United States. ▸ Based on discussions with corn ethanol players in the US, we estimate that the US could in the short term divert about 1.8 billion gallons of ethanol for SAF production, equal to 1 bgal of SAF. ▸ We have not made long-term projections on availability of corn ethanol due to uncertainties around agricultural policy and low-carbon fuel policy. We consider it possible that post-2030, life-cycle GHG reduction from corn is not deemed sufficient to meet climate goals. **Sugarcane ethanol** ▸ Due to generally having a lower CI-score compared to US corn ethanol, Brazilian sugarcane ethanol may become interesting to convert into SAF for US players. ▸ Due to uncertainties around how much sugarcane ethanol could come to the US, and threats to the US' energy security we do not include sugarcane imports in this assessment.
Initiation rate	▸ Increases from 0 plants/year in 2020 to a maximum of 5 in 2030 and stays constant until 2050. ▸ Feedstock constraint is not reached.
Lead time	5 years for a 1st commercial plant, 4 years for an nth commercial plant.
Plant output	▸ 0.2 Mt. Operating in an integrated supply chain (including alcohol production) 0.2 Mt SAF/year is high, but not unrealistic. ▸ If an AtJ facility is operated in a hub-and-spoke supply chain where cellulosic ethanol is imported from other regions, up to 1 Mt/year is thought to be feasible. For our base case, however, we adopt the WEF assumption of 0.2 Mt.
Product slate	SAF is 77% of the total output, both pre- and post-2030. This is a conservative assumption. Based on discussions and publications from technology providers we know that AtJ technologies are capable of producing a higher jet cut. We still take the WEF assumption for the base case, leaving upside potential in the scenarios

SkyNRG

Detailed assumptions for Power-to-Liquids pathway in the US until 2050

Scenario parameter	SkyNRG reflection
Feedstock availability	Drawing from the Princeton University Net Zero America study, we assume that a total of 9,825 TWh of renewable power could be available by 2050. In line with the constraints put in place for the European outlook, we assume that no more than 15% of this power supply can be used for Power-to-Liquids in aviation, meaning a constraint of about 1,500 TWh by 2050.
Initiation rate	▸ Starts to ramp up after 2025 to 20 plants/year by 2045. Capped at 20 plants, compared to 10 plants/year for the other advanced routes in total. ▸ We consider this to be very ambitious as the Fischer-Tropsch component may also have to be deployed in the Gasification + FT route. If this route becomes the dominant pathway for the bio-advanced feedstocks, then PtL may face limitations in the supply chain. ▸ Also in reality, the initiation rate is constrained by the renewable power additions that can be done, which links to the maximum plant output as well.
Lead time	4 years
Plant output	▸ 0.4 Mt. Based on SkyNRG's discussions with technology providers, we estimate that a total plant output of 0.4 Mt would require a hydrogen input of about 200 thousand tonnes. ▸ To produce this amount of hydrogen, an installed renewable power capacity of about 2+ GW offshore wind or 6+ GW of solar PV are required. Especially in combination with the initiation rates assumed, this is considered unrealistic at least until 2040. ▸ We therefore suggest to set the maximum plant output at 0.2 Mt, while noting that this is already ambitious.
Product slate	Same as Gasification + FT